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07

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ON

# THE NATURE, PROPERTIES, AND APPLICATIONS

OF

# STEAM,

AND ON

# STEAM NAVIGATION.

38W.

FROM THE SEVENTH EDITION OF THE
ENCYCLOPÆDIA BRITANNICA.

BY

JOHN SCOTT RUSSELL, M.A.F.R.S.E.
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FOR SCOTLAND, &c. &c. &c.

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# PREFACE.

THE articles STEAM and STEAM-ENGINE in the former edition of the Encyclopædia Britannica, were written by DR ROBISON. The college companion of JAMES WATT became the historian of his achievements, the expounder of inventions of which he had closely watched the origin and progress. His articles are distinguished by that clearness of conception, closeness of reasoning, and gracefulness of style, which entitle him to be ranked among the soundest and most accomplished of those authors who have contributed to the advancement of mechanical science. These articles have long formed the standards of our knowledge, and are still the fountain-head to which we resort for information. To Sir David Brewster we are indebted for the publication of certain contributions to these original articles, which have enhanced their value: to his edition of Dr Robison's works, Mr Watt himself undertook to contribute notes and additional matter, and thus became at once the historian of his own inventions and the commentator on the writings of his early friend.

Thus, the friendship of these two distinguished individuals; commencing with the warmth of youthful companionship, continuing through the vicissitudes of lives longer than the usual term of humanity, and descending into their graves—is embalmed in these their joint contributions. It appeared to the writer of these pages, that he could not better discharge the duty devolved upon him, in accepting the responsibility of the articles Steam and Steam-Engine, in the seventh edition of the Encyclopædia Britannica, than by retaining as much of those original contributions of Robison and Watt as could consist with the present advanced state of knowledge and practical art. Considerable portions of them are, therefore, presented to the reader exactly as they came from the pens of Robison* and Watt,† distinguished by their names or the accompanying marks; and to these valuable gems his own contributions serve only as the mere "setting" required to connect them with the now extensive structure of practical science.

In the joint lives and labours of Robison and Watt, we open one of the brightest pages of the "friendships of philosophy"—intellectual prowess was in them remarkably conjoined with the virtues and amiabilities of social life, and it is difficult to say, whether we more admire the philosopher, or love the man. Akin to these feelings appear to have been the sentiments with which through a long life they regarded each other. Fortunately, the records of these sentiments still exist in notices written by themselves. Robison's sketch of Watt is already before the public; but we have now the pleasure of presenting to our readers, a companion sketch of Robison drawn by Watt himself, which we owe to the kindness of Sir John Robison, and which, in April 1805, was addressed by Watt to the widow of the departed friend of his youth..

## Mr Watt's Sketch of Dr Robison.

" Our acquaintance began in 1756-7, (Mr Robison being then seventeen,) when I was employed by the University of Glasgow to repair and put in order some astronomical instruments, bequeathed to the University by Dr Macfarlane of Jamaica—Mr Robison was then a very handsome young man, and rather younger than me. He introduced himself to me, and I was happy to find in him a person who was so much better informed on mathematical and philosophical subjects than I was, and who, while he was extremely communicative, possessed a very clear method of explaining his ideas. Between two young men of ardent minds engaged in similar pursuits, a friendship was soon formed, which has continued until death has deprived me of my friend, and has suffered no other interruption than what has been caused by our absence from each other, and the necessary attention to our respective duties in life.

Soon after this, I settled as mathematical instrument maker in the college of Glasgow, and was favoured with Mr Robison's company until he left the college, about the end of 1758, and went to sea—I believe in one of his Majesty's ships.

"During this period, he turned my attention to the steam-engine, a machine of which I was very ignorant, and suggested that it might be applied to giving motion to wheel carriages, and that for that purpose it would be most convenient to place the cylinder with its open end downwards, to avoid the necessity of using a working beam. The latter idea he had published some time before in the *Universal Magazine.*—In consequence, I began a model with two cylinders, of tin plate, to act alternately by means of a * * * acting on two pinions attached to the axes of the wheels of the carriage; but the model being slightly and inaccurately made, did not answer expectation. New difficulties presented themselves; both Mr Robison and myself had other avocations requiring our attention, and neither of us having then any idea of the true principles of the machine, the scheme was dropped. I, however, went on with some detached experiments on steam until 1763, when I set about the matter more seriously, and discovered the principles upon which my improvements on the steam-engine were founded."

Beside this we place the following extract from the Eloge of Watt; being—

## Dr Robison's Sketch of Young Watt in His Workshop.

"When I was as yet a young student, I had the vanity to think myself a pretty good proficient in my favourite studies of mathematical and mechanical philosophy, and, on being introduced to Watt, was rather mortified at finding him so much my superior. Whenever any of us stumbled on a difficulty, we went to Watt; he needed but to be prompted; every thing became to him the beginning of a new and serious study, and we knew that he would not quit it till he had either discovered its insignificancy or made something of it. . . . On one occasion, the solution of a problem seemed to require the perusal of Leupold's Theatrum Machinarum—and Watt forthwith learned German; at another time, and for a similar reason, he made himself master of Italian. . . . when, to the superiority of knowledge which every man confessed, is added the *naïve* simplicity and candour of Mr Watt's character, it is no wonder that the attachment of his acquaintance was strong. I have seen something of the world, and am obliged to say, I never saw another such instance of general and cordial attachment to a person whom all acknowledged to be their superior. But this superiority was veiled under the most amiable candour and liberal allowance of merit to every man—Mr Watt was the first to ascribe to the ingenuity of a friend, things which were very often nothing but his own surmises, followed out and embodied by another. I am well entitled to say this; having often experienced it in my own case."

Below this sketch Mr Arago has written a note, to which we shall every one subscribe:—"It is difficult to determine whether the honour of having uttered these last words is not as great as that of having inspired them"—and, with both sketches before us, we are equally left in doubt whether each were not fully entitled to all the encomiums his friendship has passed on the companion of his youth and the unchanged friend of declining age.

In the present articles, it has been the author's aim to add to all that Robison had originally said of Watt's invention, what he would have required to add if he had lived to witness its present extended use, its multifarious applications, its varied forms, its modifications in materials and construction. In all else—in principles, in useful effect—little has been added, though much has been changed since the machine came out of the hands of the original inventor. The author has to regret the inadequacy of his work to the design which he had formed, and its defects, even when compared with his own standard of excellence. Unfortunately the duties of a laborious profession allow him little leisure for literary exertions. He has, however, endeavoured to place before the reader, in a simple form, all the most important information which many years of research and of practical experience in a favourite subject have placed in his possession; and the reader who is familiar with the subject will readily discover that he has read and thought for himself, and that his errors, if many, are at least his own. In one point he trusts he has facilitated the progress of the student. While giving the general reasoning of complex calculations, he has endeavoured to disembarrass them as much as possible of that parade of calculus which exhibits the author at the expense of the reader; and rather to present their results in that simple form in which alone great truths present themselves to those who thoroughly understand them. In treating an extensive subject in a limited space, he has also preferred to present general truths, rather than to enlarge upon minute details and multifarious definitions, which often lead the reader to imagine he understands a subject when he only remembers the technical phrases in which it is conveyed, having acquired nothing more than that species of mere word-knowledge deplored by Bacon—

> "Qui voces artis habeant in promptu, etiam artes ipsas perdicisse existimentur"

It is further necessary, that the intelligent reader who shall happen to compare these articles with any other treatises that may have recently appeared, should be apprized that a great part of them was written a considerable time ago, and that the commencement was actually in the press two years before the present date of publication; its alphabetical place in the Encyclopaedia, and other impediments, having delayed its appearance till now.

The author would be unjust to the editors of the Encyclopaedia Britannica did he not acknowledge the benefit this article has derived from their supervision. The multifarious duties of his profession, and prolonged absence from home and on the Continent, have in a great measure precluded his own supervision of the press. To them belong at once the merit and the responsibilities of the active editorship of these articles.

The literature as well as the science of steam navigation is still very imperfect; and this article can only be considered as contributing some materials towards a treatise on that subject. Imperfect though it be, it contains the results of many years of laborious research and personal examination and experience. The historical statements are made on the highest authority, the oral or written testimony of eye-witnesses, of the facts communicated to the author. The generalized facts of the latter part represent the qualities and performance of the *chef d'œuvres* of the best constructors, in most cases ascertained personally by the writer in his own experience, or directly communicated. Where he has committed errors or omissions, he will gratefully receive correction—especially from any kind readers who may happen to be acquainted with the merits of any one who has contributed to the advancement of steam navigation, and of whose achievements the author has the misfortune to be ignorant.

Many of the valuable drawings from which the plates were engraved, have been contributed with great kindness by the engineers whose work they are, and whose names they honour.

The reader who consults an article of an Encyclopædia, will not expect to find every thing said concerning every one of the subjects that are within its title. The following memorandum may be of service to the reader whom these pages may inspire with the wish to know more of the subject.

Mr. Farey's large quarto volume on the steam-engine, is the most satisfactory work ever published on those departments of the subject which it comprehends; but unfortunately the work is still incomplete.

Mr Stuart's historical writings on the steam-engine are well worthy of perusal. His research has been unwearied, and, although microscopic critics have detected minute errors, he is in general most trustworthy.

M. De Pambour's treatise, and Mr Robert Stephenson's, contain clear descriptions and excellent experiments on the application of the steam-engine to railway transit.

Mr Gordon's " Treatise on Elemental Locomotion," gives an interesting account of almost all that has been done for the introduction of carriages propelled by steam on common roads.

"TREDGOLD's Treatise on the Steam-Engine," contains several interesting tracts and many valuable plates.

Besides these, the engineer's library on steam now contains above a hundred volumes, for the titles of which he may consult bibliographical works. He will find interesting discussions, valuable facts, and ingenious devices in steam, spread through the journals of the last thirty years—especially in the transactions of the Royal Societies, the Philosophical Magazines, the Mechanics' Magazine, the Patent Registers, and Nautical, Railway, and Engineers' Journals;—from all of which the author has obtained much valuable information.

VIRGINIA HOUSE, GREENOCK, 23*d April* 1841.

The publishers have to add, that the *history* of Steam Navigation in this volume is not the same as that printed in the *Encyclopædia*, which is the contribution of another writer; and that, in order to render the volume on the application of steam as complete as possible, they have added the account of the Locomotive Steam-Engine, from the Treatise on Railways by Lieutenant Lecount.

# STEAM.

THE articles STEAM and STEAM-ENGINE in the Encyclopædia Britannica, were originally written by DR ROBISON, and were long the standards of reference upon these subjects. The rapid progress of science and of the mechanical arts during the present century, has now rendered it necessary to substitute for these articles those maturer results of recent research, to the attainment of which the original papers were themselves the means of very materially conducing. The value of these original researches was further enhanced by passing through the hands of the man of all others the most capable of appreciating their value, and the best qualified to increase it by his contributions. It was the early friend and companion of Professor Robison, MR WATT himself, who, towards the close of his life, and notwithstanding the laborious nature of the undertaking, agreed to revise those articles for republication, so as to present them to the public with somewhat of that greater completeness which it is to be presumed their author would himself have conferred upon them, had he lived to see the investigations which he had begun, carried forward and completed. Mr Watt was, however, prevented by the weakness of increasing years from doing more than adding notes to these articles, and they were accordingly printed in that form; but they contain a most interesting chapter of the history of inventive genius, for they give us, in Watt's own words, the history of the progress and consummation of his own noble inventions, and display the efforts of genius working its way through the obscurities of imperfect knowledge to the discovery of pure truth and the achievement of the most exquisite combinations.

While, therefore, it was impossible to retain the articles themselves, it was highly desirable that all that had rendered them valuable should be retained, and more especially such portions as serve to record the state of the mechanics and physics of steam at that time, and the progress of the invention; and these, together with the notes of Mr Watt, it has been thought better to give in the precise words of the original, than to transpose them into language which could neither be more clear nor more appropriate than that with which their authors had invested them. Such portions of the articles on steam and the steam-engine, as have been in this manner retained, are distinguished by an appropriate mark. Paragraphs from the pen of Dr Robison have a star * placed at their commencement; those of Mr Watt, in like manner, have a cross †. To all that was interesting and valuable in the original articles, an attempt has been made to superadd whatever subsequent labour and research may have brought to light.

## SECTION I.—CONSIDERATIONS OF A GENERAL NATURE REGARDING THE PROPERTIES, PHENOMENA AND APPLICATIONS OF STEAM.

1. * STEAM is the name given in our language to the visible, moist vapour which arises from all bodies which contain juices easily expelled from them by heats not sufficient for their combustion. Thus we say, the steam of boiling water, of malt, of a tan-bed. It is distinguished from smoke by its not having been produced by combustion, by not containing any soot, and by its being condensible by cold into water, oil, inflammable spirits, or liquids composed of these.

2. * We see it rise in great abundance from bodies when they are heated, forming a white cloud, which diffuses itself and disappears at no very great distance from the body from which it was produced. In this case the surrounding air is found loaded with the water or moisture which seems to have produced it, and the steam seems to be completely soluble in air, composing, while thus united, a transparent elastic fluid.

3. * But, in order to its appearance in the form of an *opaque white* cloud, the mixture with or dissemination in air seems necessary. If a tea-kettle boils violently, so that the steam is formed at the spout in great abundance, it may be observed, that the visible cloud is not formed at the very mouth of the spout, but at a small distance before it, and that the vapour is perfectly invisible at its first emission. This is rendered still more evident by fitting to the spout of the tea-kettle a glass pipe of any length, and of as large a diameter as we please. The steam is produced as copiously as without this pipe, but the vapour

is transparent and colourless throughout the whole of the pipe. Nay, if this pipe communicate with a glass vessel terminating in another pipe, and if the vessel be kept sufficiently hot, the steam will be as abundantly produced at the mouth of this second pipe as before, and the vessel will remain quite transparent. The visibility, therefore, of the matter which constitutes the steam is an accidental circumstance, and appears to require its dissemination in the air; and we know that one perfectly transparent body, when minutely divided and diffused among the parts of another transparent body, but not dissolved in it, makes a mass which is visible. Thus oil beaten up with water makes a *white opaque* mass.

4. If the column of steam which ascends from a boiler that is suddenly opened, be observed in a clear dry day, when the sun is shining, the column of vapour, gradually widening as it rises, will be observed to be of a very brilliant silvery white, and will cast a strong dark shadow upon the objects which it intercepts from the direct rays of the sun: but, if the observer be placed in this shadow, the sun will appear to him to be of a strong tawny, or fiery red colour, or, if the column be very dense, the sun will be invisible. These appearances closely resemble some phenomena of the clouds, which we know are composed of watery vapour, and which sometimes appear of a fleecy white, again of a fiery red or a burnished gold colour, or again of a dappled grey, down through every degree of darkness, until the vapour become so dense and opaque as altogether to obscure the light of the sun by a thick black cloud. These appearances have been satisfactorily accounted for. Steam, in its attenuated state, is a transparent, invisible, colourless gas. When disseminated

through the air in excessive quantities, small globules are formed, of a film of water, enclosing light vapour. These globules, floating thickly in the air, form an aggregation of minute films of fluid, capable of reflecting and transmitting light. When we are so placed that the light may be reflected to us, and when the cloud is so thick as to reflect it completely, we have the same brilliant white which results from the comminution of glass, rosin, ice, and other transparent media; and, at the same time, an observer, placed on the opposite side of the cloud, sees it as a dense black opaque mass, because the light being totally reflected, none of it can be transmitted to him. The richer colours transmitted by thinner strata of vapour are thus noticed by M. Leopold Nobili of Reggio. "The tints exhibited by the clouds in every variety of aspect are almost all comprised in Sir Isaac Newton's first ring, (the white, yellow, orange, red; or the blood, tawny, copper, ochre, and fire red, and violaceous red, or No. 1–12 of Mr Nobili's scale.) Tints of this kind do not arise from refraction and diffraction, they are produced only *by means of thin plates*. Now the measurements of Sir Isaac Newton have shown what are the dimensions of the layers of air, of water, and of glass, which produce the colours of the several rings; and, as we know that the vesicular vapours are formed of water, and that they do not reflect or transmit any other tint, we may conclude that their external film is in no case thicker than ten millionth-parts of an inch. This result appears to me to be so decidedly certain as to be entitled to a place in science." It was to the effect of thin plates on light that Newton referred the colours of all bodies; and the accounting for the rich golden hues of the clouds, and the fiery red colour of light passing through dispersed steam, by the effect of the thin plates of water enclosing the vapoury spheroids of pure steam, must be regarded as one of the most satisfactory applications of his theory. (See OPTICS.) Ency. Brit.

5. A very singular phenomenon takes place, if the flame of a candle or lamp be held below a jet of steam, as it issues from the mouth of a small pipe; the steam instantly ceases to be visible. In this case, one of two changes may be conceived to take place, either or both of which account for the permanent invisibility of the vapour: the intense heat of the flame may disperse the particles to such a distance, that there does not remain in a given space a sufficient number to form a vesicle of vapour, and it therefore remains diffused in combination with the air, which always holds a large quantity of invisible vapour, especially at high temperatures; or the vapour may be decomposed by the flame into the permanent and invisible gases of which it consists, which may again become combined, to a certain extent, with the burning substance, and support the flame.

6. * When steam is produced, the water gradually wastes in the tea-kettle, and will soon be totally expended if we continue it on the fire. It is reasonable, therefore, to suppose that this steam is nothing but water, changed by heat into an aerial or elastic form. If so, we should expect that the privation of this heat would leave it in the form of water again. Accordingly, this is fully verified by experiment; for, if the pipe fitted to the tea-kettle be surrounded with ice, or any cold substance, no steam will issue, but water will continually trickle from it in drops: and if the process be conducted with the proper precautions, the water which we thus obtain from the pipe will

be found equal in quantity to that which disappears from the tea-kettle. Steam is therefore the matter of water, converted by heat into an elastic vapour.

7. Steam, water, and ice, are three conditions of the same substance, which it assumes under different circumstances of heat and of external pressure. In each condition it obeys different laws; as a solid, ice obeys the laws of the mechanics of solid bodies: in Russia it is quarried like rock, and is used for building houses and paving ways; it is cast into moulds for domestic purposes, like iron or lead; it is painted like alabaster, and chiselled like marble: as a liquid, water is the exemplar of the hydrostatical laws of all fluids: as a vapour, it obeys the laws of aerostatics; and we now know that steam is, in all respects, similar in its constitution and phenomena to all other elastic fluids or gases. If we apply heat to a bar of extremely cold ice, it expands like other solids with heat, gradually elongating with its increased temperature, its particles receding from one another by the repulsive action induced upon them by the entrance of caloric between them, the cohesion of the particles becoming less and less, until at last, if the heat be continually thrown in, the cohesion of the particles is altogether overcome, they lose their aggregation, they become separable without effort, and, falling to pieces, the bar of ice loses its form and subsides into water. When thus melted, the water being placed in a vessel, and having heat applied to it, will, like other fluids, continue to expand from its point of greatest density, and will increase in bulk nearly one-twentieth by about 172°; but at last the entrance of so large a quantity of heat will produce a repulsive force between the particles so strong as to cause them suddenly to spring apart

from one another, so as to recede to a distance twelve times as far asunder as in the state of water, and they have now assumed the aerial condition of gas or vapour, and constituting steam, occupy 1728 times their original space. The ice passing into the condition of water, is said to be *liquefied*, and the heat necessary to convert ice into water is called the *caloric of liquidity of ice*, or the *caloric of condition of water;* when water is converted into steam, the quantity of caloric necessary for this purpose is called the *caloric of vaporization of water*, or the *caloric of elasticity of steam*, and the water is then said to *boil* or *evaporate*. This process may be reversed. If the steam have been collected in a close receptacle, it may be squeezed by external compression into its original bulk, or by cooling the outside so as to withdraw the caloric of elasticity from between the particles, they may be allowed to come together by the attraction of cohesion, and, resuming their original proximity to each other, appear once more in their former condition of water, and in this case the *vapour* is said to be *condensed;* and if the process of abstraction of caloric, with sufficient pressure, be continued, the liquid particles approaching each other, will gradually contract the bulk of the mass, and at a certain point will take again the original character of ice, and the *liquid* is then said to be *congealed* or *frozen*. The same particles of matter do "thus in turn play many parts."

Ice melts and becomes water by increment of heat.
Water evaporates into steam by increment of heat.
Steam is condensed into water by decrement of heat.
Water congeals into ice by decrement of heat.

8. These phenomena are not confined to one sub-

stance: many substances, apparently the most refractory, have been melted and again congealed, while other substances which had never been observed in any other form than that of transparent air or invisible gas have been condensed by the expedients of modern artifice into liquids heavier than water, and have even been congealed into hard and strong solids. To so great an extent has this taken place, that we are now almost warranted in deducing, from a wide induction of facts, the following generalization; that all bodies assume the solid, liquid, or gaseous condition, according to the accidents of temperature and pressure under which they happen to be placed; and that it is merely from the circumstance of their being more ordinarily found, at the present temperature of the earth and under the weight of our present atmosphere, in one of these states rather than another, that some substances have been characterised and distinguished, and classed as permanent solids, liquids, or airs. We now speak of ice only as frozen water; but had we lived under a temperature such as that which the inhabitants of the planet Jupiter, at their distance from the sun, may be conceived to endure, we should have spoken of swallowing *melted ice* as we now speak of molten lead, and a separate name for melted ice would have remained unknown; or, if we conceive, in like manner, our air to be withdrawn, and the temperature of the earth raised above 212°, we should then have moved under an atmosphere of steam of the same pressure as at present, transparent and colourless, and might only have heard of water as a curious substance obtained from the compression of the air. The phenomena of steam are much simplified and more perfectly explained when we take this enlarged view of its analogy with other kinds of matter.

9. We are most familiar with steam when in the act of rising violently from heated water in the process of *ebullition.* The history of steam at this crisis is highly instructive, and its phenomena may be studied with advantage by examining it in a glass vessel placed over a strong lamp. When heat is first applied, a rapid circulation of the fluid ensues. The water on the bottom, being first heated and expanded, becoming lighter than the rest, rises to the top, and is replaced by the current of colder water descending to receive in its turn a further accession of heat. By and by, small globules of steam, formed on the bottom and surrounded by a film of water, are observed adhering to the glass ; as the heat increases they enlarge; in a short time several of them unite, form a bubble larger than the others, and, detaching themselves from the glass, rise upwards in the fluid. But they never reach the surface ; they encounter currents of water still comparatively cold, and descending to receive from the bottom their supply of heat, and encountering them, the bubbles are robbed of their heat, shrivel up into their original bulk, and are lost among the other particles of water. In a short time the mass of the water becomes more uniformly heated; the bubbles, becoming larger and more frequent, are condensed with a loud crackling noise ; and at last, when the heat of the whole mass reaches 212°, the bubbles from the bottom rise without condensation through the water, swell and unite with others as they rise, and burst out upon the air in a copious volume of steam, of the same heat as the water from which they are formed, and pushing aside the air, make room for themselves. In this process, by continuing the application of heat, the whole of the water may be "boiled away" or converted into steam.

10. The singular sounds produced from a vessel of

water exposed to heat, previously to boiling, have attracted attention; the water is then vulgarly said to be simmering or singing; and, when this takes place, it is because the vessel is boiling at one place and comparatively cold at another. This noise is most distinctly heard when the fire or flame applied is small, and its heat intense, when the vessel is large and the water deep; for in that case the entrance of the caloric will take place more rapidly than the circulation can convey it to the remote particles of fluid, and so bubbles of steam will form rapidly at one place and be rapidly condensed at another; the degree of velocity with which such bubbles succeed will determine the pitch of the singing tone. We have observed this phenomenon in greatest perfection when we have attached a slender pipe to a close boiler producing steam, and carried its open mouth, of the diameter of $\frac{1}{8}$ or $\frac{3}{16}$ of an inch, down below the surface of cold water in a glass jar. When the mouth of the steam-pipe is held just below the surface of the water, the steam issues with great rapidity in small bubbles, producing an acute tone; and, on the other hand, when the pipe is held at a considerable depth, the concussions become more violent and louder, their intervals of succession greater, the tone is lowered, and finally, the shocks become detached, and so violent as to shake the glass and surrounding objects with much force. On this subject Professor Robison observes, that a violent and remarkable phenomenon appears, if we suddenly plunge a lump of red-hot iron into a vessel of cold water, taking care that no red part be near the surface. If the hand be now applied to the side of the vessel, a most violent tremor is felt, and sometimes strong thumps; these arise from the collapsing of very large bubbles. If the upper part of the iron be too hot, it warms the surrounding water so much that the bubbles from below come up through it uncondensed, and produce ebullition without concussion. The great resemblance of this tremor to the sensation which we experience during the shock of an earthquake, has led many to suppose that the latter is produced in the same way; and their hypothesis, notwithstanding the objections which we have elsewhere stated to it, is by no means unfeasible. Any obstruction on the bottom of a boiler, on the inside, as a piece of metal or stone introduced among the water, may produce a succession of smart concussions, by the sudden condensation of gas collected under it.

11. The permanence of the boiling point is one of the most remarkable of the phenomena of ebullition. When water has once been brought to boil in an open vessel, it is not possible to make the water sensibly hotter, however strongly the fire may be urged or its intensity increased. This circumstance is very striking, because we know that heat continues to be thrown in exactly as fast as before the boiling point, and that in that case the heat rose rapidly, whereas now it has altogether ceased to increase. If a thermometer of mercury, air, oil, or metal be placed among the water, the temperature will constantly increase, and expand the matter of the thermometer, until the water boils; and then, whether it boil slowly or rapidly, with a strong fire or a gentle one, the thermometer will continue to stand at the same point. This point is so well defined, as to furnish our standard for the comparison of temperatures, and is the same on all thermometers, being called *the boiling point*, although it is differently numbered on each, being called 212° on our common thermometer or

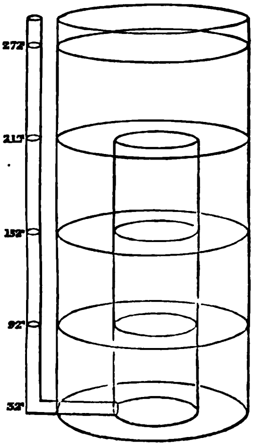
Fahrenheit's, 80° on Reaumur's, and 100° on the centigrade thermometer.

It is also to be remarked, that the temperature of the steam issuing from boiling water is the same with the temperature of the water itself, and remains equally invariable; so that all the steam produced from water boiling at 212° is itself at 212°. This remark will assist us in accounting for the disposal of the heat which the fire gives out during the time of ebullition; for it is manifest that the heat is all the while carried off by the large volumes of steam, at a temperature of 212°, that are diffused through the air; and so it happens that an increase of heat in the fire, instead of increasing the heat of the water, only increases the volumes of the steam thrown off, and the quantity of heat carried away. This view of the subject is confirmed by a simple experiment. Take a strong glass flask, place water in it, and a thermometer among the water, and let it be held over a lamp until the water boil, and the thermometer will be observed rising till it reach 212°, when the steam will begin to escape rapidly from the neck of the flask. Let it now be corked tightly, and the heat continually applied; and it will be observed that the thermometer does not now stand at 212°, but rises rapidly from that point up to 220° and 230°, showing that the free escape of the steam into the open air is necessary to the permanence of the boiling point. If the heat be still applied, the experiment may be rendered still more instructive, by suddenly pulling out the cork of the flask, when the vapour will instantly rush out in a large volume, and the thermometer sink down to 212°, showing that all the excess of heat has been carried off by the steam into the air.

12. We have thus seen that a large quantity of heat may be given out to the particles of a certain quantity of water, converting them into steam, and yet that the thermometer shall afford no indication of this quantity. As soon as water boils, the whole mass is heated up to 212°; and although the same heat that produced the ebullition be still continually applied, and although we know that this heat must be continually entering into the water, still it is not detected, or in any way exhibited by the thermometer. On this account, the heat given to water during ebullition is said to become *latent*, or lie hid from the thermometer; and, indeed, the thermometer merely indicates the intensity of heat, the calorimeter alone can measure its quantity. The quantity of heat given out to water after it has begun to boil, is more than five-fold that which is sufficient to bring it from the freezing up to the boiling point; for, if we continue the fire with the same intensity that was used in bringing it to boil, it will require more than five-fold that duration and quantity of fuel to boil all the water away, or convert it all into steam of 212° of heat. Thus the sensible heat, added from 32°, will be 180°, and that latent in the steam is more than five-fiold; or, in other words, the *insensible caloric* in steam is five-fold its *sensible* heat; or the same quantity of matter in the condition of steam at 212°, and of water at 212°, will hold different quantities of caloric, in the proportion of about 6 to 1. This is called the greater *capacity of steam for caloric* than of water for that substance; and it is in part accounted for, by the greater distances of the particles of the matter of steam and water from each other in the former than the latter condition; for when the distances of the particles are increased 12 times, the

spheres of caloric around each atom may be much larger, without increased elasticity of the calorific fluid. Dr Black was the discoverer of the admirable doctrine of *latent heat.*

Fig. 1.



13. Dr Dalton has thus illustrated the doctrine of latent heat, and of the increased capacity of a liquid for holding caloric, when it passes into the condition of vapour. The liquid and its vapour may be considered as two reservoirs of caloric, capable of holding different quantities of that fluid. Let figure 1. represent to us such an arrangement; the internal cylinder of smaller capacity, the external one of enlarged capacity surrounding and extending far above it, and a small open tube of glass, communicating freely at the bottom with the internal cylinder. Let us now conceive water to be poured into the internal cylinder, the water will manifestly flow into the slender tube till it stand on the same level in the tube as in the cylinder. If any additional quantity be now poured into the internal cylinder, the rise of water in the slender glass tube will serve as an index of the quantity of added fluid; and when it is filled to the top, the fluid will stand at the height marked 212°, and will still be a correct index of the addition of fluid. But if more water be now added to it, it will not make its appearance in the slender tube, but will simply overflow from the internal cylinder over into that of enlarged capacity, so that, while

a large quantity is passing into the vessel and gradually filling it up to 212°, no additional rise takes place until the whole of the outer cylinder become filled to that point, after which any further addition will again become sensible, by a corresponding rise in the tube. This process is in precise analogy to the succession of circumstances in heating a liquid, and converting it into steam. The internal cylinder represents the liquid, the external one the vapour of greater capacity, and the slender glass tube at the side the thermometer placed in communication with them. When heat flows into the liquid, it passes equally into the thermometer; and each increment of the one produces an equal increment in the other, until the liquid reaches the limit of its capacity, when it suddenly begins to enlarge its bulk and take the form of steam; but the quantity of heat required to fill up this enlarged capacity is so great, as to require about 5½ times as much to fill it as was contained in the whole liquid before, so that all this time the thermometer is standing still, and it is not until the whole of the steam is thus supplied with 212° of caloric, that the thermometer will begin to show any further elevation; after which, any increment of heat thrown into the steam will make its appearance on the thermometer, and proceed as formerly, by simultaneous increments.

14. It appears, therefore, that the cause why water boiling under the open air does not reach a higher temperature than 212°, is, that the steam which is raised by any additional heat, carries that additional quantity of heat along with it into the air. But here a question occurs at once to the enquirer into these phenomena, viz. Why does water require to be heated up to 212° before it will throw off its increments of heat and vapour into the

air ? Why does not steam rise equally strongly from water at 200° or 180° ? The categorical reply is, that the elastic force of the heat is not sufficient to enable the steam to force its way against the pressure of the air until it reaches this point. In order to understand the means by which we arrive at this conclusion, it is necessary to know that, when the pressure of air on the surface of the water is artificially diminished, the steam does actually rise, and the water bubbles and boils with great violence, at temperatures far below 212°. It is only when the surface of the water is exposed to the full *pressure of the air* in a common vessel that it is prevented from rising in vapour, at temperatures lower than the usual boiling point. If the surface of the hot water be protected from the pressure of the air, by being placed under a glass shade, and the air removed from the inside of it by an air-pump, the water may be made to boil at all temperatures below 212°. The following table contains the results of a series of experiments made, with great care, by Dr Dalton, towards the end of last century, in order to ascertain how much of the whole pressure of the air it was necessary to remove, in order

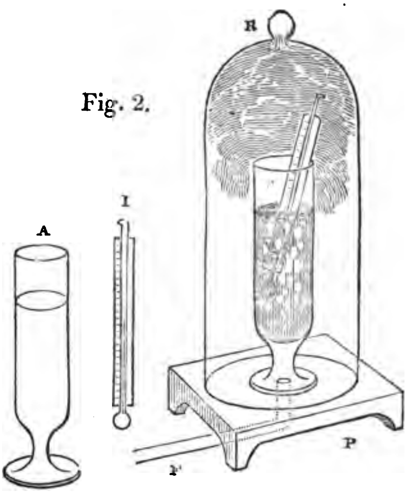


Fig. 2.

to make water boil at a given temperature. In order to understand the way in which this table was formed, the reader must conceive a vessel of water first of all boiling at 212° in the open air, as the vessel A in figure 2, the thermometer I being placed in it. After allowing the water to cool to 200°, let the vessel of water and the immerged thermometer be now placed on the plate stand P of an air-pump, and covered over with a strong glass receiver R; and let a portion of the enclosed air be now withdrawn by the pump from the inside of the receiver by the pipe F; and suppose that there are in all 30 cubical inches, or other volumes, of air in the receiver at first; then the water being at 200°, when about 7 out of the 30 parts of the air have been withdrawn, leaving only about 23 parts out of 30 pressing on the water, it will be observed instantly to commence giving off steam in rapid ebullition. If next the process be repeated, only allowing the water to cool to 190°, the ebullition will not commence in this lower temperature till about 12 out of the 30 volumes of air have been withdrawn; and if, in a third experiment, the water be cooled down to 180°, the elastic force communicated by this degree of heat will not be capable of overcoming the resistance arising from the pressure of the air, until one-half of the original pressure of 30 has been removed. To this process there is no limit; for as we go on lowering the temperature, we can always find a point at which the water will boil, provided the counteracting pressure be sufficiently diminished. The following is Dr Dalton's table, containing the results of his experiments, as given in his *Meteorology*, in 1793:—

| Heat of the Water when boiling under diminished Pressure. | Quantity of Pressure of Air remaining on the Fluid. |
|---|---|
| 212° | 30·0 |
| 200 | 22·8 |
| 190 | 18·6 |
| 180 | 15·2 |
| 170 | 12·2 |
| 160 | 9·45 |
| 150 | 7·48 |
| 140 | 5·85 |
| 130 | 4·42 |
| 120 | 3·27 |
| 110 | 2·52 |
| 100 | 1·97 |
| 90 | 1·47 |
| 80 | 1·03 |

15. In vacuo, therefore, or under a rarefied atmosphere, the boiling point of water is lower than 212°. Now, the barometer informs us, that the pressure of our atmosphere is not constantly the same; it has normal and abnormal variations; it has horary, and menstrual, and annual variations. It frequently stands at 30 inches, sometimes at 31 inches; and, on the morning of the 7th of January 1839, it was observed at Edinburgh, by Sir John Robison, to be as low as 27 inches and six tenth-parts. Now, on that morning, water would have been found to boil in the open air at about 208°, instead of 212°; and for every depression of the barometer, there is a corresponding depression of the boiling point. This variation of the boiling temperature with the variation of the barometer, and of the corresponding density of the air, is important: and the following short table shows the changes which take place within the limits of the usual variations of the weather:—

When the barometer stands at 31·8, water boils at 215°
..................................31·2,..................214
..................................30·6,..................213
..................................30· inches,............212
When the barometer falls to 29·4,..................211
..................................28·8,..................210
..................................28·2,..................209
..................................27·7,..................208
And at 27·2, it would boil at 207

But these extremes are probably greater than have ever been observed on the ordinary level of this country.

16. There is yet another variation of circumstance which affects the point of ebullition, and that is, distance from the centre of the earth and height above the level of the sea. It is well known, that, on the summit of a mountain, the pressure of the air is less than on a plain, and still less there than at the bottom of a pit or deep valley. It is now equally well known, that the cause of this is the very limited height to which air in a dense state covers the earth, the whole atmosphere being equivalent to not more than 5 miles in depth of such air as we breathe; and it is hence obvious, that after a vertical ascent of a mile to the top of a mountain, there would be only about $\frac{4}{5}$ of the atmosphere remaining above the person on its summit. One of the highest of the Andes has been ascended to such a height, that there remained only $\frac{13}{30}$ of the whole atmosphere above the observer. Now, in this case, the barometer, instead of being sustained at 30 inches; its usual height, had fallen to 13 inches, because, according to the constitution of the barometer, the height of the column of mercury in it is proportional to the quantity

of air resting above it.* Hence, a barometer being carried up a mountain by an observer, falling as he ascends, enables him to ascertain the height of his ascent. This he does with perfect precision, so as to determine accurately the height of any point of the mountain to which he has ascended, and where he has noticed the fall of the barometer from the point where it stood when at the bottom, by means of an allowance of nearly 100 feet of height for every tenth part of an inch that the barometer has fallen, as explained more fully under the heads BAROMETER and ATMOSPHERE.

The steam of water may be rendered the means of determining the height of a mountain, on the principle of diminished atmospheric pressure, so as to act as a substitute for the barometer. We have just seen that water gives off steam by ebullition, above or below the temperature 212°, according as the pressure of the atmosphere is greater or less than the standard pressure which sustains the barometer at 30 inches. And we have already given a table, (Arts. 14 and 15,) showing how much the boiling point was raised or depressed by diminishing the pressure of the atmosphere. On consulting Dr Dalton's table, we see that, when $\frac{15}{30}$ of the air were removed, water boiled at so low a temperature as 180°. This, therefore, would show that, if water boiled on the top of any mountain at 180°, the barometer would stand there at a height of little more than 15 inches; and if at the bottom of the mountain water boiled at 212°, showing the barometer to be then at 30 inches, a similar allowance of height being made, viz. about 1000 feet for each inch, or 15,000 feet, would be a rude approximation to the true height. The table at the end of the third section, and the rules under the head **Barometer** in the Encyclopædia Britannica will enable any one who studies this subject to form rules for closer approximation; but the following table will be of use to those who may merely wish to put it in practice.

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* See Articles BAROMETER, PNEUMATICS, and ATMOSPHERE, in the Encyclopædia Britannica.

*Rule for finding heights by boiling water.*—Boil pure water in an open vessel at the bottom of the elevation, and observe on the thermometer the point at which it boils. Boil it again at the top of the mountain, and observe with the thermometer the point at which it now boils: the difference of temperature, multiplied by 530 feet, will give a close approximation to the height of the upper above the lower station.

This will give an approximation; but, if greater accuracy be required, it will further be necessary to correct for the difference of the temperature of the air at the two stations, in the following manner. Add the temperatures of the air at the stations, and subtract 64 from their sum, multiply the remainder by one thousandth part of the height found; and this will be the correction to be added to the height formerly found. The result thus found will still require a slight correction for the figure of the earth and latitude of the place; but this does not amount to more in our latitude than an addition of about two feet in a thousand, which forms a second correction. This method is, however, to be regarded only as an approximation, for which all the corrections given under the head **Barometer** would be necessary, in order to render it equally perfect with observations by that instrument. In short, this method may be considered as a telltale on the barometer, showing where the barometer would stand if placed in its position. Thus, if water boil at 200° on the top of a mountain, that is merely to be considered as indicating that the barometer, if placed there, would stand at 22·8;

after which, the process of deducing the height remains the same. To illustrate the mode of deducing heights from the boiling point, as we have given it, we take the following example.

Water boils on the top of Ben Nevis at 203·8°, while at the side of the Caledonian Canal it boils at 212°, the temperature being 30° on the summit of the mountain, and 35° below. In order to determine the height,

| | |
|---|---|
| From 212° | |
| Take 203·8° | To 30° |
| ——— | Add 35° |
| There remains 8·2° | —— |
| Multiply by 530 | Sum 65° |
| ——— | Subt. 64° |
| 246·0 | —— |
| 410 | Remain 1° mult. by 4·346 |
| ——— | |
| 4346 first approx. | Latitude 56° nearly |
| 4 first correct. | Mult. 4·350 |
| ——— | by 2· |
| 4350 second approx. | —— |
| 8·7 second correct. | 8·700 |
| ——— | |

Calc. height, 4358·7 third approximation.
4358· true measured height—the difference being less than 1 foot.

This method, however, is seldom susceptible of so high a degree of accuracy, even with the most carefully conducted experiments.

17. This method of determining heights by the ebullition of water is not a recent invention. It was suggested originally by Mr Fahrenheit, in the 33d volume of the

*Philosophical Transactions,* in a paper entitled "*Barometri Novi Descriptio.*" The subject was further matured by Cavallo, who has written concerning it in the 71st volume of the same Transactions; and the method has finally received from the Rev. F. J. H. Wollaston the highest degree of perfection of which it seems to be capable. His paper, read before the Royal Society on the 6th of March, 1817, and afterwards published in the Philosophical Transactions of that year, gives an account of the very beautiful and ingenious apparatus which he has contrived for facilitating the procedure of taking the observations with the requisite precision. Fig 4 is a view of the whole apparatus, consisting principally of a tripod stand, surrounded by a sort of tent cover, which is quite essential for the protection of the lamp from the strong winds generally encountered at considerable altitudes. The lamp acts on a small tin vessel, which is a cylinder 5½ inches deep and 1⅓ in diameter, the sides of which are double, leaving an interstitial space of confined air to prevent cooling. Above this vessel is a circular plate of metal G H K, to which the thermometer is to be fixed; and the scale and neck of the thermometer are seen projecting above the stand. A (fig. 3) represents the thermometer made use of, which it is desirable to have of as strong and as compact a construction as possible, while, at the same time, its degrees should range as extensively as possible. These desiderata are attained in his construction. The bulb A, one inch in diameter, is blown thick and strong, on the end of a tube about $\frac{1}{40}$ of an inch in diameter: close above the bulb, is a cavity B, swelled out to such a size as to contain whatever mercury will expand out of the bulb, between 32° and the lowest temperature at which the mercury is likely to boil at such altitudes as it will be used to measure. It is this which renders the instrument compact; because, if it be not taken out of the British islands, it will never, in all probability, boil at less than 200°; and thus the whole length of the stalk is left for a range of 12° or 15° of the thermometer. In the instrument figured, the scale R is 5 inches long, $\frac{9}{10}$ of an inch wide, and a length of 4·15 inches is divided into 100 parts, which by a vernier reads off to 1000 parts, being 241 parts to an inch; so that 1° Fahr. corresponds to 233 parts on the scale, or to 530 feet.

Fig. 3.

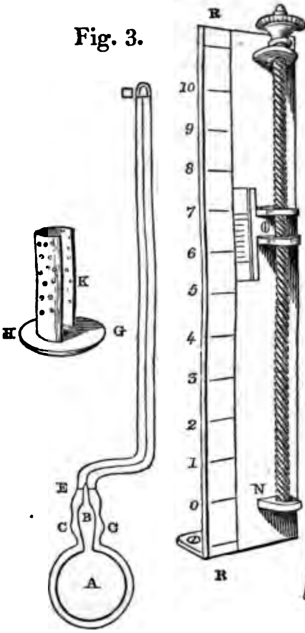
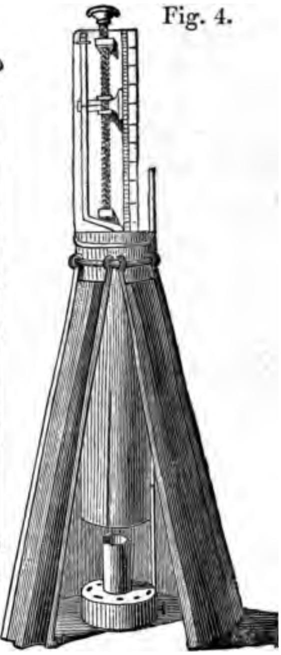


Fig. 4.



Each part of the scale, as read by the vernier, will therefore correspond to 2·275 feet, being about half the degree of minuteness of the mountain barometer divided into thousandths, each of which is nearly equivalent to one foot of height. The accuracy, however, of this scale is probably greater than the degree of accuracy of which the method of observation is itself capable.

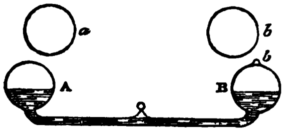
Whether an observer have or have not the means of obtaining such an instrument as this, it will be, in many cases, useful to travellers to be provided with means, more or less accurate, of making observations of this nature, on the summit of such mountains as they may have the opportunity of visiting. For this purpose, the most convenient is a small cooking apparatus, such as will supply the wants of a traveller ; consisting of a round tin stand, protecting a lamp, in which a small quantity of the traveller's supply of spirituous liquid may be burnt, so as to boil some of the water of a small bottle, which he has also carried with him, or perhaps a little melted snow. An umbrella or waterproof cloak will screen the whole from the wind ; and a thermometer should have been procured, with a stem as minutely divided as possible, and should be inserted, by means of a small cork, in an aperture of the lid left on purpose. The quantity of the water may be small, and it will serve a culinary purpose immediately after the operation is completed. The thermometer should be inserted only among the steam. The traveller must take great precautions for striking a light, as he will find this much more troublesome in the cold rarefied air of a mountain summit than below.

18. Distillation is a method of separating a liquid from extraneous matter, by first of all converting it into steam,

and then condensing that steam so as to form the liquid. Different substances take the liquid form at various temperatures; and, therefore, the heat may be so regulated that only one substance of a mixture shall take the form of vapour, and being conveyed by a pipe through a vessel of cold water, or otherwise exposed to the cooling process, the vapour being condensed will give the pure liquid. A great improvement upon the process of separating liquids has been successfully introduced by Mr Howard. It consists of *distillation or evaporation in vacuo,* and has been most usefully employed in the refining process of sugar. When sugar is dissolved in water, it requires a much higher temperature than 212° to boil the mixture, or to convert the water into steam and separate it from the solid; and as the process goes on, and the solution comes to hold less and less water, the requisite degree of heat is further augmented, until the temperature becomes so high as to injure the colour and otherwise deteriorate the article of merchandise in its crystallized state. Instead of this increased temperature, Mr Howard places the syrup in vacuo, and thus boils it at a low and innoxious heat. This he accomplishes by pumping out the air and vaporized water from the close boiler, by means of a large air-pump driven by machinery. The process has produced a great improvement on this article of commerce, and has remunerated its inventor with an ample fortune.

Distillation in vacuo is peculiarly adapted to obtaining those delicate extracts and essential oils from vegetable substances, which are apt to suffer deterioration from the usual high temperatures.

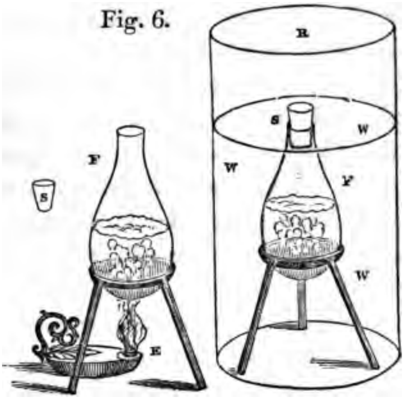
Fig. 5.



19.* The pulse glass, an invention attributed to Dr Franklin, is an apparatus illustrating beautifully the process of ebullition in vacuo at low temperatures. If two glass balls, A and B (fig. 5) be connected by a slender tube, and one of them, A, be filled with water, a small opening or pipe *b* being left at the top of the other, and this be made to boil, the vapour produced by it will drive all the air out of the other, and will at last come out itself, producing steam at the mouth of the pipe. When the ball B is observed to be occupied by transparent vapour, we may conclude that the air is completely expelled. Now, shut the pipe by sticking it into a piece of tallow or wax, the vapour in B will soon condense, and there will be a vacuum. The flame of a lamp and blow-pipe being directed to the little pipe *b*, will immediately cause it to close and seal hermetically. We have now a pulse glass. Grasp the ball A in the hollow of the hand; the heat of the hand will immediately expand the bubble of vapour which may be in it, and this vapour will drive the water into B, and then will blow up through it for a long while, keeping it in a state of violent ebullition, as long as there remains a drop or film of water in A. But care must be taken that B is all the while kept cold, that it may condense the vapour as fast as it rises through the water. Touching B with the hand, or breathing warm on it, will immediately stop the ebullition. When the water in A has thus been dissipated, grasp B in the hand; the water will be driven into A, and the ebullition will take place there as it did in

B. Putting one of the balls into the mouth will make the ebullition more violent in the other, and the one in the mouth will feel very cold. This is a pretty illustration of the rapid absorption of the heat by the particles of water which are thus converted into elastic vapour. We have seen this little toy suspended by the middle of the tube like a balance, and thus placed in the inside of a window, having two holes, *a*, *b*, cut in the pane, in such a situation, that, when A is full of water and preponderates, B is opposite to the hole *b*. Whenever the room became sufficiently warm, the vapour was formed in A and immediately brought the water into B, which was kept cool by the air coming into the room through the hole *b*. By this means B was made to preponderate in its turn, and A was then opposite to the hole *a*, and the process was now repeated in the opposite direction. This amusement continued as long as the room was warm enough. Instead of water, alcohol or ether may be substitued, and will act more readily.

Fig. 6.



20. The following experiment, where ebullition is produced by the application of cold, is instructive. A Florence flask F, is about $\frac{1}{3}$ full of water, and is placed over a lamp E until the water boils; and when the steam

has been rising for a short time violently from the neck of the vessel, the cork S is to be applied as a stopper, and must fit with great accuracy. The flask thus closed is to be set aside for a few minutes till it have cooled considerably, and is then to be suddenly placed on a stand in the cold water W, contained in the glass reservoir R. The ebullition in the flask will recommence with a degree of violence proportioned to the coldness of the water W.

The theory of this action is simple. When the flask is plunged in the cold water, $\frac{2}{3}$ of its contents are steam: the chill water condenses it into water, it shrinks up into 1-1728th part of its bulk, and would leave 1727 parts out of 1728 vacuous; but the warm water being now in vacuo, throws up in rapid ebullition (according to Art. 14) copious volumes of vapour of its own temperature, which is again, by coming into contact with the sides of the vessel, and by directly giving off its heat to the water, chilled into water, and so in succession all the vapour thus sent up is in turn reconverted into water, and the vacuum sustained, until at last, the equilibrium between the temperature of the water, within and around the flask, having been established, the interchange of caloric ceases; and even now, if the flask were plunged into freezing water, the ebullition would recommence as violently as before.

21. We have already noticed (Art. 11) the fact, that, when water is confined in a close vessel, and heat is applied to it, the water will not boil even at a temperature of 212°. If heat be continually thrown into the water in this state, the particles will acquire a very high temperature; and, at the same time, the tendency of the enclosed fluid to burst the vessel will become very great. The following experiment upon this subject is one of the most

interesting and the earliest of which we are in possession. It was published in 1663 by the Marquis of Worcester, and we give it in his own words. "I have taken a piece of a whole cannon, whereof the end was burst, and filled it three quarters full, stopping and screwing up the broken end, as also the touch-hole, and making a constant fire under it; within twenty-four hours it burst, and made a great crack."

It is in virtue of the great elastic force by which water, when heated, tends to expand into 1728 times its bulk, in the form of steam, that this element has become a mechanical mover, subject to the control of man. There are two great principles upon which such machines are constructed; the one commonly called high-pressure steam-engines, and the other low-pressure steam-engines.

In a high-pressure steam-engine, the principal source of motion is the *elastic force* of steam, formed by water, raised to a high temperature in confined vessels, and tending to escape from them with such force, as to impart motion and movement to solids or fluids, ingeniously arranged to receive from it velocity or direction required for the accomplishment of some end.

In a low-pressure steam-engine, the principal source of power is derived from using steam merely for the purpose of forming a vacuum. For this purpose steam is admirably calculated. It is only necessary to allow the steam of a liquid to enter any vessel filled with air; and if there be left an aperture of escape, the steam, entering in abundance, will push the air out before it. When the air has wholly escaped, it only remains necessary to close all the openings of the vessel, and allow it gradually to cool down, when the steam will be condensed, will shrivel up in the form of water into the 1728th part of its bulk, leaving the other 1727 parts vacuous. The mechanical force of a vacuum on the earth's surface is well known: it will raise water to a height of more than 30 feet, and support 15 lbs. on every square inch of surface exposed to it. Whatever, therefore, the formation of a vacuum on the earth's surface can effect, of that is the force of steam capable at low pressure, scarcely exceeding the temperature of 212°. Hence the low-pressure engine is sometimes called the condensing engine, because it acts principally by condensation of steam to form a vacuum. The high pressure of steam, and its vacuum-forming power, are frequently used in combination.

22. There are other properties of steam, besides its mechanical force, that render its use of great practical value. Its great capacity for heat enables it to take up, at one time, and in one place, a large quantity of heat which it may be employed as a vehicle to transfer, at a subsequent period and at a distant point, to some other substance. It is thus rendered an economizer, distributer, and reservoir of heat derived from the combustion of fuel. In this view it has great value as an agent in distributing the heat used for warming buildings, heating baths, evaporating solutions, distilling, brewing, drying, dyeing, and even for domestic cookery, and the means of extracting wholesome and nutritious food from most unpromising and unpalatable materials.

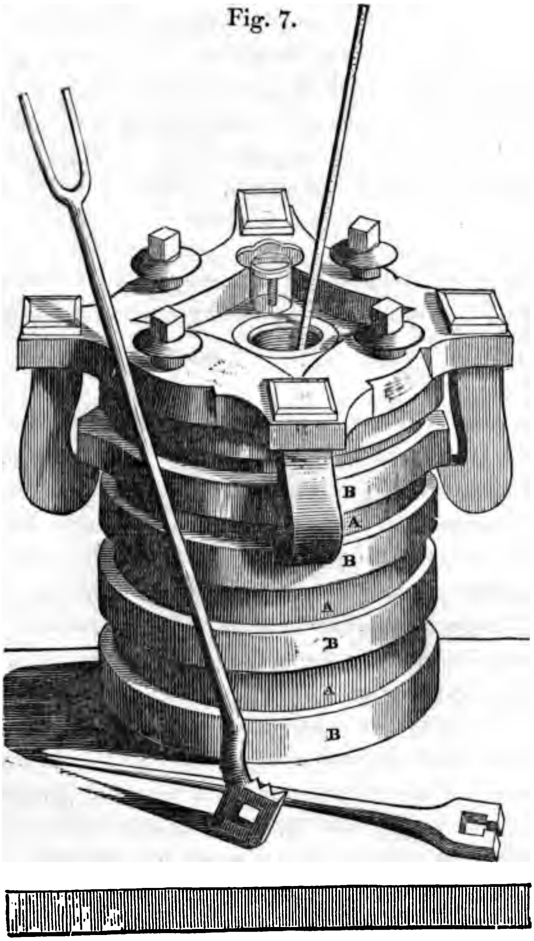
In order, however, to its successful application as a mechanical power, and its profitable use in each of the various functions which it is capable of performing, it is necessary to study its various phenomena in greater detail; to obtain an intimate acquaintance with its properties; to determine its laws in the various relations of space, time, and quantity; how much heat it requires, what fuel it consumes, what force it exerts, how fast it will move, how it will condense, expand, and contract, and what relation it bears to the different fluids from which it may be derived. Each of these enquiries, and the manner in which each of these objects may be most satisfactorily attained, is the subject of one or other of the following sections of this article.

## SECT. II.—EXPERIMENTAL RESEARCHES CONCERNING THE ELASTIC FORCE OF STEAM AT DIFFERENT TEMPERATURES.

23. The earliest researches we have met with into the phenomena of steam, undertaken with the philosophical purpose of obtaining experimental data for the scientific investigation of its properties and relations, are to be met with in a scarce work, printed at Basle in 1769, and entitled, "*Specimen physico-chemicum de Digestore Papini; Primitias experimentorum novorum circa fluidorum a calore rarefactionem et vapoream elasticitatem exhibens, &c. Auctore Jo. Henrico Ziegler.*" His experimental boiler consisted of a copper vessel (fig. 7) AA, silvered internally, and belted externally with massive iron hoops BB. A strong framework of iron, attached to the upper hoop, gives support to the circular cover B, (fig. 8,) in which there are an opening P for admitting water, another D into which an elaterometer is inserted, consisting of a bottle G containing mercury, and a glass tube *c c* cased in iron, open at both ends, and immersed in the mercury at the bottom; the

third or central aperture E being occupied by a copper tube EF, closed below, and containing oil or other viscid liquid,

Fig. 7.



to act as a bath for the bulb of the thermometer F and its

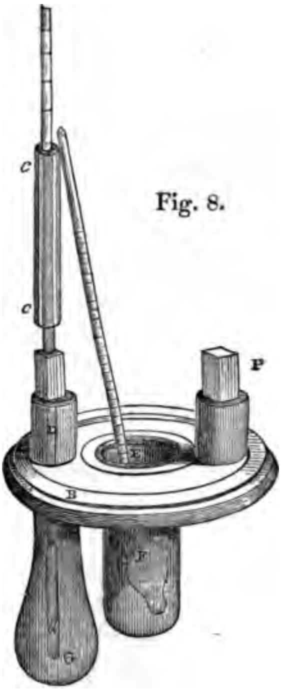


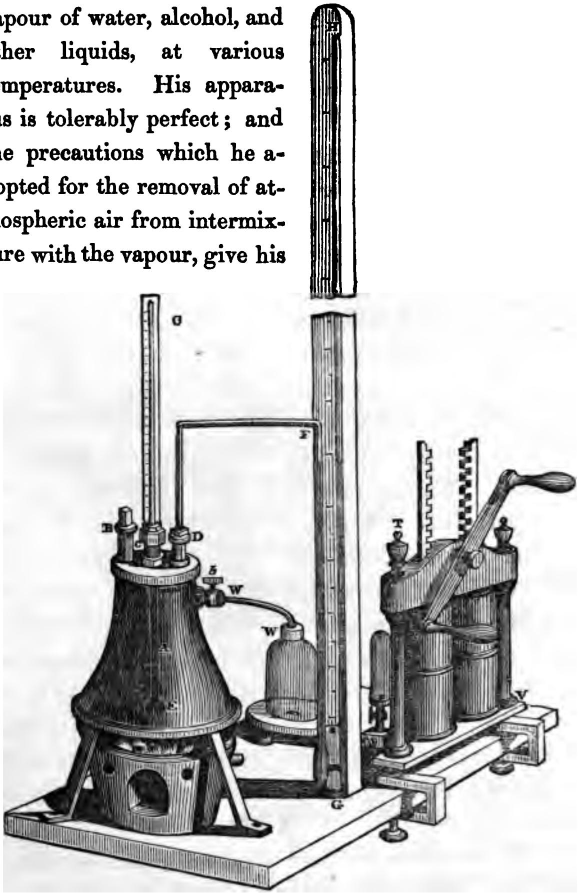
Fig. 8.

protector from the pressure of the vapour. The method of using this apparatus was as follows. The digester being partly filled with water, closed and placed on the fire, the generation of the steam would raise the oil or mercury in the bath E to the temperature of the water and steam within, so as to give to the thermometer F an indication of the temperature; and, at the same time, the elastic force of the steam flowing or moving by would raise it in C to a certain number of inches, so as to cause the corresponding pressure. This apparatus is both appropriate and ingenious, and indicates considerable mechanical knowledge in its inventor, a physician of Wintrethour in Switzerland. Unhappily he lived too remote from the scene of the philosophical discoveries of that period, to adopt the precautions necessary to give value to his experiments. He allowed atmospheric air to mingle with the steam to such an extent as greatly to vitiate his results.

24. M. Betancourt visited England about the end of last century; and having been employed to select machines, models, and drawings for the Spanish government, made himself acquainted with the use of steam in Great

Britain at that period. On his return, he immediately undertook a series of experiments on the force of the vapour of water, alcohol, and other liquids, at various temperatures. His apparatus is tolerably perfect; and the precautions which he adopted for the removal of atmospheric air from intermixture with the vapour, give his experiments considerable value and precision. Some of his experiments were made in vacuo; and he seems to

Fig. 9.



have been one of the first philosophers who examined the production of steam at temperatures below the ordinary point of ebullition, under the pressure of the atmosphere. His experiments extend from 32° up to 279°, being 67° above the ordinary boiling point.

His apparatus (fig. 9) consisted of a spheroidal copper boiler A, about eight inches in diameter, fifteen inches high, and a tenth of an inch in thickness; a flat cover was soldered on the top of it, and three apertures were formed into which were inserted a thermometer EC, a glass tube D, and a plug B, for admitting water. The glass tube being bent downwards at F, was recurved upwards at G, leaving an upright stem, ten feet high, and hermetically sealed at the top, so as to leave a perfect vacuum in that end of the tube, over a column of mercury of about 30 inches in the two branches of the recurvation at the bottom. The boiler was provided with a stop-cock *b*, by which the air was extracted from the boiler previous to experiment, by means of an air-pump TV, communicating with W; and when this was accomplished so as to obtain a vacuum on both ends of the mercurial column, the mercury stood, as in the figure, on nearly the same level, in both its branches. The fire was instantly applied, and the crackling noise which followed informed him that the ebullition had commenced, and the steam in the boiler pressing on that end of the mercurial column nearest to it, raised the other in the vacuum a certain quantity above its outer level, indicating its elastic force, which gradually increased until it became at the usual heat of boiling water, equal to twenty-eight French inches, the mean pressure of the atmosphere. The following table will enable us to estimate the value of these experiments; it is given in degrees of Reaumur's thermometer, of which 0° coincides with 32° of our common scale, and 80° with our boiling point 212° Fahrenheit, each degree of Reaumur being equal to 2¼ of our scale. The pressure is in French inches of mercury :—

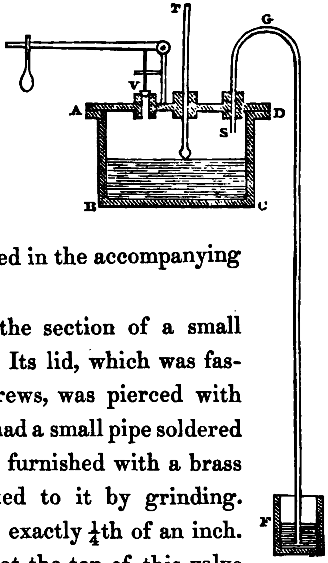
| Degrees of Fahrenheit. | Reaumur's Scale. | First Series of Observations. | Second Series of Observations. |
|---|---|---|---|
| | | Inches of Mercury. | Inches of Mercury. |
| 32° | 0° | 0·0 | 0·0 |
| 43·25 | 5 | 0·05 | 0·02 |
| 54·50 | 10 | 0·17 | 0·15 |
| 65·75 | 15 | 0·35 | 0·35 |
| 77·00 | 20 | 0·62 | 0·65 |
| 88·25 | 25 | 1·00 | 1·05 |
| 99·50 | 30 | 1·50 | 1·52 |
| 110·75 | 35 | 2·12 | 2·15 |
| 122·00 | 40 | 2·90 | 2·92 |
| 133·25 | 45 | 4·00 | 3·95 |
| 144·50 | 50 | 5·50 | 5·35 |
| 155·75 | 55 | 7·55 | 7·32 |
| 167·00 | 60 | 10·10 | 9·95 |
| 178·25 | 65 | 13·25 | 13·20 |
| 189·50 | 70 | 17·50 | 16·90 |
| 200·75 | 75 | 22·35 | 21·75 |
| 212·00 | 80 | 28·60 | 28·00 |
| 223·25 | 85 | 37·00 | 36·45 |
| 234·50 | 90 | 47·20 | 46·40 |
| 245·75 | 95 | 58·20 | 57·80 |
| 257·00 | 100 | 72·40 | 71·80 |
| 268·25 | 105 | 84·90 | 86·80 |
| 279·50 | 110 | 98·00 | 98·00 |

The slight deviation of these experiments from each other indicates considerable accuracy of experiment; and the slight excess in the former of the two series, is attributed to the formation of a less perfect vacuum at the commencement of the observations, arising from the smaller quantity of water in the boiler when the experiments were made.

It should, however, be noticed, that there is one omission of some importance in the experiments of M. Betancourt. He inserts the *bare bulb* of his thermometer into the reservoir among the water, so as to suffer all the variations imposed on it by the varying elasticity of the steam. By following the method adopted by his predecessor, M. Ziegler, of inserting a metallic tube to sustain the pressure of the steam, and forming it into a mercurial bath for containing the thermometer, and so transmitting the heat of the steam to it without exposure to variable pressure, a source of considerable error might have been avoided. This precaution is essential to a good set of experiments on steam; for a very slight pressure, even of the finger, on the bulb of a thermometer, will raise it several degrees.

25. Of British philosophers, Dr Robison was one of the first to make accurate and systematic experiments on the phenomena of the temperature and elastic force of steam. They appear to have been made in 1778. His apparatus is represented in the accompanying figure.

Fig. 10.



* ABCD (fig. 10) is the section of a small digester made of copper. Its lid, which was fastened to the body with screws, was pierced with three holes, each of which had a small pipe soldered into it. The first hole was furnished with a brass safety-valve V, nicely fitted to it by grinding. The area of this valve was exactly $\frac{1}{4}$th of an inch. There rested on the stalk at the top of this valve the arm of a steelyard carrying a sliding weight. This

arm had a scale of equal parts, so adjusted to the weight, that the number on the scale corresponded to the inches of mercury, whose pressure on the under surface of the valve is equal to that of the steelyard on its top; so that when the weight was at the division 10, the pressure of the steelyard on the valve was just equal to that of a column of mercury 10 inches high, and $\frac{1}{4}$th of an inch base. The middle hole contained a thermometer T firmly fixed into it, so that no vapour could escape by its sides. The ball of this thermometer was but a little way below the lid. The third hole received occasionally the end of a glass pipe SGF, whose descending leg was about 36 inches long. When this syphon was not used, the hole was properly shut with a plug.

* The vessel was half filled with distilled water, which had been purged of air by boiling. The lid was then fixed on, having the third hole S plugged up. A lamp being placed under the vessel, the water boiled, and the steam issued copiously by the safety-valve. The thermometer stood at 213°, and a barometer in the room at 29·9 inches. The weight was then put on the fifth division. The thermometer immediately began to rise; and when it was at 220, the steam issued by the sides of the valve. The weight was removed to the 10th division; but, before the thermometer could be distinctly observed, the steam was issuing at the valve. The lamp was removed further from the bottom of the vessel, that the progress of heating might be more moderate; and when the steam ceased to issue from the valve, the thermometer was at 227. The weight was now shifted to 15; and, by gradually approaching the lamp, the steam again issued, and the thermometer was at 232½. This mode of trial was continued all the way to the 75th division of the scale. The expe-

riments were then repeated in the contrary order; that is, the weight being suspended at the 75th division, and the steam issuing strongly at the valve, the lamp was withdrawn, and the moment the steam ceased to come out, the thermometer was observed. The same was done at the 70th, 65th division, &c. These experiments were several times repeated both ways; and the means of all the results for each division are expressed in the subjoined table, where column 1st expresses the elasticity of the steam, being the sum of 29.9; and the division of the steelyard, column 2d, expresses the temperature of the steam corresponding to this elasticity.

| Elasticity. | Temperature. |
|---|---|
| 35 inches. | 209° |
| 40 | 226 |
| 45 | 232 |
| 50 | 237 |
| 55 | 242 |
| 60 | 247 |
| 65 | 251 |
| 70 | 255 |
| 75 | 259 |
| 80 | 263 |
| 85 | 267 |
| 90 | 270½ |
| 95 | 274½ |
| 100 | 278 |
| 105 | 281 |

* A very different process was necessary for ascertaining the elasticity of the steam in lower temperatures, and consequently under smaller pressures than that of the atmosphere. The glass syphon SGF was now fixed into its hole in the lid of the digester. The water was made to boil smartly for some time, and the steam issued copiously both at the valve and at the syphon. The lower end of the syphon was now immersed into a broad saucer of mercury, and the lamp instantly removed, and every thing was allowed to grow cold. By this the steam was gradually condensed, and the mercury rose in the syphon, without sensibly sinking in the saucer. The valve and all the joints were smeared with a thick clammy cement,

composed of oil, tallow, and rosin, which effectually prevented all ingress of air. The weather was clear and frosty, and the barometer standing at 29.84, and the thermometer in the vessel at 42°. The mercury in the syphon stood at 29.7, or somewhat higher, thus showing a very complete condensation. The whole vessel was surrounded with pounded ice, of the temperature 32°. This made no sensible change in the height of the mercury. A mark was now made at the surface of the mercury. One observer was stationed at the thermometer, with instructions to call out as the thermometer reached the divisions 42, 47, 52, 57, and so on by every five degrees till it should attain the boiling heat. Another observer noted the corresponding descents of the mercury by a scale of inches, which had its beginning placed at 29.84 from the surface of the mercury in the saucer.

* The pounded ice was now removed, and the lamp placed at a considerable distance below the vessel, so as to warm its contents very slowly. These observations being very easily made, were several times repeated, and their mean results are set down in the following table: only observe, that it was found difficult to note down the descents for every fifth degree, because they succeeded each other so fast. Every 10th was judged sufficient for establish-

| Temperature. | Elasticity. | Temperature. | Elasticity. |
|---|---|---|---|
| 32° | 0.0 | 130° | 3.95 |
| 40 | 0.1 | 140 | 5.15 |
| 50 | 0.2 | 150 | 6.72 |
| 60 | 0.35 | 160 | 8.65 |
| 70 | 0.55 | 170 | 11.05 |
| 80 | 0.82 | 180 | 14.05 |
| 90 | 1.18 | 190 | 17.85 |
| 100 | 1.61 | 200 | 22.62 |
| 110 | 2.25 | 210 | 28.65 |
| 120 | 3.00 | | |

ing the law of variation. The first column of the table contains the temperature, and the second the descent (in inches) of the mercury from the mark 29.84.

Four or five numbers at the top of the column of elasticities, are not so accurate as the others, because the mercury passed pretty quickly through these points. But the progress was extremely regular through the remaining points; so that the elasticities corresponding to temperatures above 70° may be considered as very accurately ascertained.

* Not being altogether satisfied with the method employed for measuring the elasticity in temperatures above that of boiling water, a better form of experiment was adopted. Indeed it was the want of other apparatus which made it necessary to employ the former. A glass tube was procured of the form represented in Fig. 11, having a little cistern L, from the top and bottom of which proceeded the syphons K and MN. The cistern contained mercury, and the tube MN was of a slender bore, and was about six feet two inches long. The end K was firmly fixed in the third hole of the lid, and the long leg of the syphon was furnished with a scale of inches, and firmly fastened to an upright post.

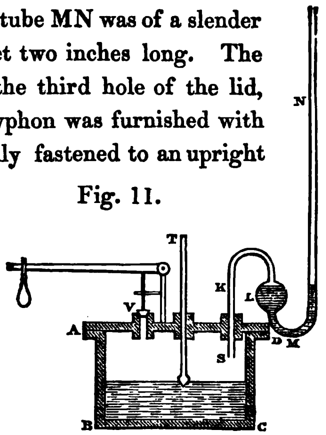


Fig. 11.

The lamp was now applied at such a distance from the vessel as to warm it slowly, and make the water boil, the steam escaping for some time through the safety-valve. A heavy weight was then suspended on the steelyard; such as it was known that the vessel would support, and, at the same time, such as would not allow the steam to force the mercury out of the long tube. The thermometer began immediately to rise, as also the mercury in the tube MN. Their correspondent stations are marked in the following table.

| Temperature. | Elasticity. |
|---|---|
| 212° | 0.0 |
| 220 | 5.9 |
| 230 | 14.6 |
| 240 | 25.0 |
| 250 | 36.9 |
| 260 | 50.4 |
| 270 | 64.2 |
| 280 | 76.0 |

This form of the experiment is much more susceptible of accuracy than the other, and the measures of elasticity are more to be depended on. In repeating the experiment, they were found much more constant; whereas, in the former method, differences occurred of two inches and upwards.

* We may now connect the two sets of experiments into one table, by adding to the numbers in his last table the

| Temperature. | Elasticity. | Temperature. | Elasticity. |
|---|---|---|---|
| 32° | 0.0 | 160° | 8.65 |
| 40 | 0.1 | 170 | 11.05 |
| 50 | 0.2 | 180 | 14.05 |
| 60 | 0.35 | 190 | 17.85 |
| 70 | 0.55 | 200 | 22.62 |
| 80 | 0.82 | 210 | 28.65 |
| 90 | 1.18 | 220 | 35.8 |
| 100 | 1.6 | 230 | 44.5 |
| 110 | 2.25 | 240 | 54.9 |
| 120 | 3.0 | 250 | 66.8 |
| 130 | 3.95 | 260 | 80.3 |
| 140 | 5.15 | 270 | 94.1 |
| 150 | 6.72 | 280 | 105.9 |

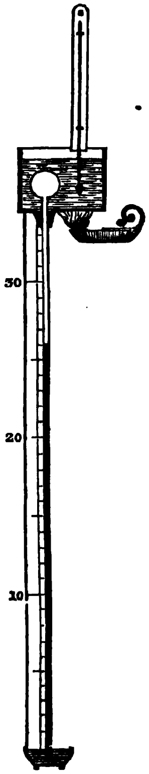
constant height 29.9, which was the height of the mercury in the barometer during the last set of observations.

26. In the mean time, however, Mr Watt had been led, in the course of his invention of the steam-engine, to make experiments on the elastic force of steam, of which he has given the following account, and which was annexed by himself to Dr Robison's original article in the Encyclopædia Britannica.

† In the winter of 1764–5, I made experiments at Glasgow on the subject, in the course of my endeavours to improve the steam-engine, and as I did not then think of any *simple* method of trying the elasticities of steam at temperatures less than that of boiling water, and had at hand a digester by which the elasticities at greater heats could be tried, I considered that, by establishing the ratios in which they proceeded, the elasticities at lower heats might be found nearly enough for my purpose. I therefore fitted a thermometer to the digester, with its bulb in the inside, placed a small cistern with mercury also within the digester, fixed a small barometer tube with its end in the mercury, and left the upper end open. I then made the digester boil for some time, the steam issuing at the safety-valve, until the air contained in the digester was supposed to be expelled. The safety-valve being shut, the steam acted upon the surface of the mercury in the cistern, and made it rise in the tube. When it reached to 15 inches above the surface of the mercury in the cistern, the heat was 236°; and at 30 inches above that surface, the heat was 252°. Here I was obliged to stop, as I had no tube longer than 34 inches, and there was no white glass made nearer than Newcastle-upon-Tyne. I

therefore sealed the upper end of the tube hermetically whilst it was empty, and when it was cool immersed the lower end in the mercury, which now could only rise in the tube by compressing the air it contained. The tube was somewhat conical; but, by ascertaining how much it was so, and making allowances accordingly, the following points were found, which, though not exact, were tolerably near for an *aperçu.* At 29½ inches (with the sealed tube) the heat was 252°, at 75½ inches the heat was 264°, and at 110½ inches 292°. (That is, after making allowances for the pillar of mercury supported, and the pillar which would be necessary to compress the air into the space which it occupied, these were the results.) From these elements I laid down a curve, in which the abscissæ represented the temperatures, and the ordinates the pressures, and thereby found the law by which they were governed, sufficiently near for my then purpose. It was not till the years 1773–4, that I found leisure to make further experiments on this subject, of which, though I do not consider the results as accurate, I shall give an account here, as they were in point of date prior to any others that I was then acquainted with.

Fig. 12.



† A tin pan, of about five inches in diameter and four inches deep, had a hole made in its bottom, near one side,

and in this hole was soldered a socket somewhat conical, which nearly fitted a barometer tube with which the experiments were to be made. This tube was about 36 inches long, and had a ball at one end about 1½ inches diameter, the contents of which were nearly equal to those of the stem of the tube; some paper was lapped round the tube near the ball, and it was forced tight into the conical socket of the pan, so that the ball was within the latter, at such a height that it might be immersed in water. The tube and pan were then inverted, and the ball was filled with clean mercury, and the stem with distilled water fresh boiled. The tube was re-inverted, so that the ball and pan were uppermost; the lower end of the tube being shut by the finger, the water ascended into the ball, and the mercury occupied the tube. The lower end of the latter being then placed in a cistern of mercury, and released from the finger, the mercury and water descended, and the ball was left partly empty: being agitated in this position, and let stand some time, much air was extricated from the water; the tube was inclined as much as it could be, and again inverted, the air let out, and its place supplied with boiling water. It was again placed with the ball uppermost, the end of the tube stopped, the pan filled with hot water, which was made to boil by means of a lamp; the lower end of the ball being placed in the cistern, and released from the finger, the mercury descended into the cistern, but upon the water in the pan being suffered to cool, partly rose again into the tube. Much air was thus liberated, and more was got rid of by agitation, in the manner of the water-hammer, and by leaving it standing for some time erect, until at last I got it so free from air, that when I raised it upright, it supported a column of mercury 34 inches high; and no vacuum was formed until it was violently shaken, when it fell down suddenly and settled at 28.75 inches, but upon being inclined, a speck of air always remained, though, when it was expanded by a pillar of mercury 27 inches high, this speck was not larger than a pin's head.

† In this state, when the tube was perpendicular, I found the mercury to stand at 28.75 inches, the column of water above it was about 6½ inches, = half an inch of mercury. The whole then being 29.25 inches, when the stationary barometer stood at 29.4, the difference, or pillar supported by the elasticity of the steam = 0.15 inch. The water in the pan was then heated exceedingly slowly by a lamp, and stirred continually by a feather to make the heat as equal as possible. The results are shown in the following table :—

TABLE, No. I.

| Heats. | Elasticities. | Heats. | Elasticities. | Heats. | Elasticities. | Heats. | Elasticities. |
|---|---|---|---|---|---|---|---|
| | Inches. | | Inches. | | Inches. | | Inches. |
| 55° | 0.15 | 135° | 4.53 | 167° | 11.07 | 187° | 17.51 |
| 74 | 0.65 | 142 | 5.46 | 172 | 11.95 | 189 | 18.45 |
| 81 | 0.80 | 148 | 6.40 | 175 | 12.88 | 191 | 19.38 |
| 95 | 1.30 | 153 | 7.325 | 177.5 | 13.81 | 193.5 | 20.34 |
| 104 | 1.75 | 157 | 8.25 | 180 | 14.73 | 196.5 | 21.26 |
| 118 | 2.68 | 161 | 9.18 | 182.5 | 15.66 | | |
| 128 | 3.60 | 164 | 10.10 | 185 | 16.58 | | |

At this time (1774) I tried a set of experiments in the same manner on a saturated solution of common salt. When this solution was perfectly saturated by boiling, and was put into the tube, it precipitated a quantity of salt which disturbed the experiment. I was therefore obliged to take it out, and filter it, during which process it attracted moisture from the air, and appeared, by its boiling point, not to be perfectly saturated. Though it was more free from air than water is, yet it parted from what it contained with great difficulty, and would part with none when shaken as a water-hammer, though it opened in all parts of the liquor. The result of this experiment is contained in the annexed table :—

TABLE, No. II.—*Stationary Barometer*, 29.5.

| Heats. | Elasticities. | Heats | Elasticities. | Heats. | Elasticities. | Heats. | Elasticities. |
|---|---|---|---|---|---|---|---|
| | Inches. | | Inches. | | Inches. | | Inches. |
| 46° | 0.01 | 154° | 5.36 | 187° | 12.67 | 208° | 20.86 |
| 76 | 0.36 | 160 | 6.27 | 193.5 | 14.5 | 210 | 21.8 |
| 85 | 0.58 | 165 | 7.2 | 195.5 | 15.34 | 212 | 22.74 |
| 92 | 0.81 | 169 | 8.12 | 198.5 | 16.25 | 214 | 23.66 |
| 113 | 1.72 | 173 | 9.03 | 201.5 | 17.16 | 216 | 24.6 |
| 129 | 2.63 | 177 | 9.94 | 203.5 | 18.1 | 218 | 25.52 |
| 139 | 3.54 | 180 | 10.85 | 205.5 | 19.03 | 220 | 26.5 |
| 147 | 4.45 | 183 | 11.76 | 207 | 19.94 | | |

In the same manner I tried a set of experiments upon spirit of wine, the results of which are contained in the annexed table :—

TABLE, No. III.

| Heats. | Elasticities. | Heats. | Elasticities. | Heats. | Elasticities. | Heats. | Elasticities. |
|---|---|---|---|---|---|---|---|
| | Inches. | | Inches. | | Inches. | | Inches. |
| 34° | 0.22 | 120° | 7.12 | 146.5° | 15.03 | 164° | 22.59 |
| 40 | 0.929 | 124.5 | 8.46 | 148.5 | 15.974 | 166 | 23.53 |
| 67 | 1.897 | 128 | 9.4 | 151 | 16.908 | 167 | 24.47 |
| 84 | 2.806 | 132 | 10.34 | 152.5 | 17.85 | 168 | 25.4 |
| 95 | 3.744 | 135 | 11.32 | 155 | 18.8 | 169 | 26.35 |
| 103 | 4.728 | 139 | 12.21 | 157 | 19.75 | 171 | 27.3 |
| 110 | 5.63 | 141.5 | 13.15 | 160 | 20.71 | Stat. Bar. 29.4 | |
| 114 | 6.58 | 144 | 14.1 | 162.5 | 21.65 | | |

Upon considering the probable cause of the difference, especially in the lower heats, between my experiments and those of Mr Southern, related in his letter annexed to this essay, I can only reconcile them by supposing that the stationary barometer, with which the comparison was made, had its scale placed 0.2 of an inch too low, and by adding that quantity to the elasticities in table 1st, they approach nearly to Mr Southern's experiments.

If that conjecture is adopted, the same addition will be necessary to tables 2d and 3d, as they were compared with the same stationary barometer.

To determine the heats at which water boils when pressed by columns of mercury above 30 inches, a tube of 55 inches long was employed: one end was put through a hole in the cover of a digester, and made tight by being lapped round with paper; and, within the digester, the end of the tube was immersed in a cistern of mercury. A thermometer was fixed in another opening, so that the bulb was in the inside of the digester, and the stem and scale without; and the bulb was kept half an inch from the cover of the digester by a wooden collar. The cover being fixed on tight, and the digester half filled with water, it was heated by means of a large lamp.

† The air in the upper part of the digester expanding by heat, the column of mercury in the tube was considerably raised by that expansion before the water boiled. The air was let out, and the water heated to boiling; still however, some air remained, for the mercury stood at 213½°. That deduction being made, the following table shows the heats and corresponding elasticities:—

| Heats. | Elasticities. | Heats. | Elasticities. | Heats. | Elasticities. | Heats. | Elasticities. |
|---|---|---|---|---|---|---|---|
| 213° | 30 | 228° | 39 | 240° | 49 | 259° | 66 |
| 215 | 31 | 229.5 | 40 | 242.5 | 50 | 261 | 68 |
| 217 | 32 | 231 | 41 | 244.5 | 52 | 262.5 | 70 |
| 219 | 33 | 232.5 | 42 | 247 | 54 | 264.5 | 72 |
| 220.5 | 34 | 234 | 43 | 248.5 | 56 | 266.5 | 74 |
| 222 | 35 | 235 | 44 | 250.5 | 58 | 268 | 76 |
| 223.5 | 36 | 236.5 | 45 | 252.5 | 60 | 269.5 | 78 |
| 225 | 37 | 237.5 | 46 | 255 | 62 | 271 | 80 |
| 226.5 | 38 | 238.5 | 47 | 257 | 64 | 272.5 | 82 |

In making these experiments, the digester was heated very slowly, and the heat was kept stationary as much as was possible at each observation, so that the whole series occupied some hours. The degrees of elasticity were observed by my friend Dr Irvine, whilst I observed those of the thermometer in all these experiments.

With the whole of the observations, I was, after all, by no means satisfied, as I perceived there were irregularities in the results which my more urgent avocations did not permit me to explore the causes of and to correct.

The matter remained in that state till 1796, when I requested Mr Southern to try them over again, in the performance of which he was assisted by Mr William Creighton. The results of these observations are contained in Mr Southern's letter to me, which follows this memoir; and, from the very great care with which the experiments were made, the known accuracy of both Mr Southern and Mr Creighton, and the agreement of the experiments with one another, I have reason to believe them as nearly perfect as the subject admits of. The method he adopted of trying the elasticities above the temperature of boiling water by a piston, accurately fitted to a cylinder, is much to be preferred to that adopted by Dr Robison, and is more manageable under great elasticities than that of a long pillar of mercury.

27. The reference which is here made applies to the following letter from Mr *Southern* to Mr Watt :*—

" DEAR SIR,—The experiments, of which the particular circumstances are hereafter related, were made in 1803, with the view of ascertaining chiefly the density of steam raised from water under different pressures above that of the atmosphere, an apparatus having then been made for a different purpose, which seemed pretty well adapted to this object.

" Besides the experiments now to be related, in which the temperature of steam raised under *high* pressures was observed in 1803, others had been made some years before, in 1797 and 98, for that purpose only ; and, as they were made with the greatest circumspection, both the manner of making them and their results may be here described, as may also the results of other experiments, made with equal care, to ascertain the temperature of steam raised under *low* pressures.

" The instrument used in the former was a Papin's digester, similar to what you had used ; the leading differences being in adapting a metallic tube to it to contain the thermometer, or rather as much of it as contained mercury, in the manner mentioned in the beginning of this letter, and instead of a valve, by the load on which to measure the elasticity of the contained steam, a nicely bored cylinder was applied, with a piston fitting it, so as to have very little friction, and to the rod of this was applied a lever, constructed to work on edges like those of a scale-beam, by which the resistance against the elastic force of the steam could be accurately determined; and at your suggestion, to be assured that no inaccuracy had crept into the calculation by which this resistance, through the medium of the lever, was ascertained, an actual column of mercury of 30 inches high was substituted, and the correspondence was found to be within $\frac{1}{100}$ of an inch.

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* In all these experiments Mr Southern was assisted by Mr William Creighton.

"The observations at each of the points of pressure noted were continued some minutes, the temperature at each being alternately raised and lowered, so as to make the pressure of the steam on the under side of the piston alternately too much and too little for the weight with which it was loaded; and thence a mean temperature was adopted, the extremes of which were, as well as I now recollect, not more than half a degree on each side of it. The load on the piston, including its own weight, &c., &c., was calculated to be successively just equal to 1, 2, 4, and 8 atmospheres of 29.8 inches of mercury each, and the temperature of the steam was varied, as above, till that of each point was determined; the results were thus:—

| Atmospheres. | Pressure in inches of Mercury. | Temperatures. |
|---|---|---|
| 1 | 29.8 | 212° |
| 2 | 59.6 | 250.3 |
| 4 | 119.2 | 293.4 |
| 8 | 238.4 | 343.6 |

" The experiments for ascertaining the temperature of steam below the atmospheric pressure were made with an apparatus essentially similar to that which you originally used, and with scrupulous care and attention: and I met with the same incidents as you had done; such as, the production of a bubble of air whenever, after any experiment, the tube was inclined to refill the ball; and also the extraordinary suspension of a column of mercury of 35 inches vertical height, and of 7 inches of water above that, although the counterpoise was only that of the atmosphere, then under 30 inches. I found also that the tube required a considerable degree of taboring, or shaking, to make the column subside and leave a space in the ball. This phenomenon was not produced till after much pains taken in inverting and re-inverting the tube again and again, nor till it had been suffered, after these operations, to stand for three or four days undisturbed in the exhausting position, and then discharging the air that had been accumulating in the interval.

" The results to be found in the table below, were deduced from the observations as you had done—viz., by adding to the height of the column of mercury in the tube (ascertained by a gauge floating on the surface of the mercury in the basin), that of the water above it, or rather of an equivalent column of mercury, and subtracting their sum from the height of the common barometer at the time. All these results were taken from observations made after the apparatus had been so perfectly exhausted of air as to produce the phenomenon just mentioned.

| Temperature. | Elasticity. | | | |
|---|---|---|---|---|
| | 1st Set. | 2d Set. | 3d Set. | Mean. |
| | Inches. | Inches. | Inches. | Inches. |
| 52° | 0. | 0.42 | 0.40 | 0.41 |
| 62 | 0.53 | 0.52 | 0.52 | 0.52 |
| 72 | 0.73 | 0.73 | 0.73 | 0.73 |
| 82 | 1.03 | 1.02 | 1.02 | 1.02 |
| 92 | 1.42 | 1.41 | 1.42 | 1.42 |
| 102 | 1.98 | 1.92 | 1.95 | 1.95 |
| 112 | 2.67 | 2.63 | 2.66 | 2.65 |
| 122 | 3.58 | 3.54 | 3.58 | 3.57 |
| 132 | 4.68 | 4.65 | 4.72 | 4.68 |
| 142 | 6.05 | 6.00 | 6.14 | 6.06 |
| 152 | 7.86 | 7.80 | 7.89 | 7.85 |
| 162 | 9.98 | 9.96 | 10.04 | 9.99 |
| 172 | 12.54 | 12.72 | 12.67 | 12.64 |
| 182 | 16.01 | 15.84 | 15.88 | 15.91 |

" The following formula will be found to give the elasticity belonging to a given temperature, and *vice versa*, with a sufficient degree of accuracy for most purposes, within the range of the experiments, at least, from which they have been formed.

Let $t$ = temperature, $e$ = elasticity, in inches of mercury ;
$T = t+52$, and $E = e-\frac{1}{10}$, $m = 94250,000000$ ;

Then $$\frac{T^{5.14}}{m} = E$$

$$.\sqrt[5.14]{Em} = T$$

" But as the calculation is most easily performed by logarithms, let L signify the logarithm of the quantity to which it is prefixed :

$$\text{Then}\quad 5.14\,LT - 10.97427 = LE$$

$$\frac{LE + 10.97427}{5.14} = LT.$$

" The following table shows the observed elasticities, those derived from calculation by the formula, and the differences of the two, which appear to me to be as small as can be expected, taking a general view.

| Temperature. | Observed Elasticities. | Calculated Elasticities. | Differences. |
|---|---|---|---|
| | Inches. | Inches. | Inches. |
| 32° | | 0.18 | |
| 42 | | 0.25 | |
| 52 | | 0.35 | |
| 62 | 0.52 | 0.50 | —0.02 |
| 72 | 0.73 | 0.71 | —0.02 |
| 82 | 1.02 | 1.01 | —0.01 |
| 92 | 1.42 | 1.42 | 0.00 |
| 102 | 1.95 | 1.96 | +0.01 |
| 112 | 2.65 | 2.67 | +0.02 |
| 122 | 3.57 | 3.58 | +0.01 |
| 132 | 4.68 | 4.74 | +0.06 |
| 142 | 6.06 | 6.20 | +0.14 |
| 152 | 7.85 | 7.99 | +0.14 |
| 162 | 9.99 | 10.19 | +0.20 |
| 172 | 12.64 | 12.86 | +0.22 |
| 182 | 15.91 | 16.08 | +0.17 |
| 192 | . . . | 19.91 | . . . |
| 202 | . . . | 24.45 | . . . |
| 212 | 29.80 | 29.80 | 0.00 |
| 250.3 | 59.60 | 59.69 | +0.09 |
| 293.4 | 119.20 | 118.32 | —0.88 |
| 343.6 | 238.40 | 237.60 | —0.80 |

" I believe it is now generally considered that the temperature 212° is that of water boiling when the barometer is at 30 inches instead of 29.8; and if, in the above algebraic expressions, the following alterations be made, the results from the formulæ will correspond with the adjustment of that point, and fully as well with the experiments generally.

" Let $T=t+51.3$; the index of the power and of the root be 5.13, instead of 5.14; and $m = 87344,000000$. So the two last equations will be: $5.13\ LT - 10.94123 = LE$; and $\frac{LE + 10.94123}{5.13} = LT$.

" The table will stand as follows, supposing the thermometer had been graduated for 212° to correspond with 30 inches of the barometer:—

| Temp. | Observd. Elasticities. | Calcul. Elasticities. | Differences. | Temp. | Observd. Elasticities. | Calcul. Elasticities. | Differences. |
|---|---|---|---|---|---|---|---|
| | Inches | Inches. | Inches. | | Inches. | Inches. | Inches. |
| 32° | *0.16 | 0.18 | +0.02 | 142° | 6.10 | 6.22 | +0.12 |
| 42 | *0.23 | 0.25 | +0.02 | 152 | 7.90 | 8.03 | +0.13 |
| 52 | *0.35 | 0.35 | 0.00 | 162 | 10.05 | 10,25 | +0.20 |
| 62 | 0.52 | 0.50 | —0.02 | 172 | 12.72 | 12.94 | +0.22 |
| 72 | 0.72 | 0.71 | —0.01 | 182 | 16.01 | 16.17 | +0.16 |
| 82 | 1.02 | 1.01 | —0.01 | 192 | . . . | 20.04 | . . . |
| 92 | 1.42 | 1.42 | 0.00 | 202 | . . . | 24.61 | . . . |
| 102 | 1.96 | 1.97 | +0.01 | 212 | 30.00 | 30.00 | 0.00 |
| 112 | 2.66 | 2.68 | +0.02 | 250.3 | 60.00 | 60.11 | +0.11 |
| 122 | 3.58 | 3.60 | +0.02 | 293.4 | 120.00 | 119.17 | —0 83 |
| 132 | 4.71 | 4.76 | +0 05 | 343.6 | 240.00 | 239.28 | —0.72 |

" I remain, with the greatest esteem and respect,

" Dear Sir,

" Your very obedient Servant,

"*Oakhill*, *26th March* 1814." " JOHN SOUTHERN.

" To JAMES WATT, Esq., Heathfield."

28. In the *Memoirs of the Royal Academy of Berlin* for 1782, there is an account of some experiments made by M. Achard on the elastic force of steam, from the temperature 32° to 212°. They agree extremely well with those mentioned here, rarely differing more than two

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* These are inserted from numerous experiments made by Mr W. Creighton.

or three tenths of an inch. He also examined the elasticity of the vapour produced from alcohol, and when the elasticity was equal to that of the vapour of water, he found that the temperature was about 35° lower. Thus, when the elasticity of both was measured by 28.1 inches of mercury, the temperature of the watery vapour was 209°, and that of the spirituous vapour was 173°. When the elasticity was 18.5, the temperature of the water was 189.5°, and that of the alcohol 154.6°. When the elasticity was 11.05, the water was 168°, and the alcohol 134.4° Observing the difference between the temperature of equally elastic vapours of water and alcohol not to be constant, but gradually to diminish, in M. Achard's experiments, along with the elasticity, it became interesting to discover whether, and at what temperature, this difference would vanish altogether. Experiments were accordingly made by the writer of this article, similar to those made with water. They were not made with the same scrupulous care, nor repeated as they deserved, but they furnished rather an unexpected result. The following table will give the reader a distinct notion of them.

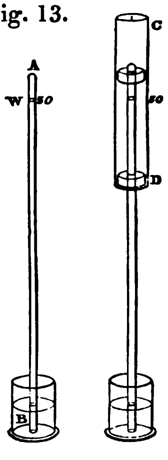
| Temperature. | Elasticity. | Temperature. | Elasticity. |
|---|---|---|---|
| 32° | 0.0 | 140° | 12.2 |
| 40 | 0.1 | 160 | 21.3 |
| 60 | 0.8 | 180 | 34. |
| 80 | 1.8 | 200 | 52.4 |
| 100 | 3.9 | 220 | 78.5 |
| 120 | 6 9 | 240 | 115. |

29. Dr Dalton appears to have been the first to escape from the natural enough error of assuming that the vapour of water at 32° would be = 0. His apparatus is the most simple and refined of any that have been em-

ployed for temperatures below 212°, and his experiments are those which, to the present day, have the greatest authority. Dr Dalton's first experiments were published in 1793, in his *Meteorological Essays;* afterwards, when more extended, in the *Manchester Memoirs*, 1802; then in the first volume of his *System of Chemistry*, 1808; and finally in the second volume of the same work, 1827. The following is the account given by himself, of his early experiments, in the *Manchester Memoirs.*

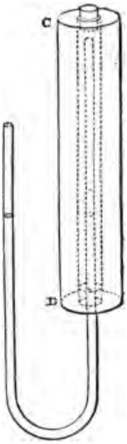
"My method is this: I take a barometer tube AB, (Fig. 13,) perfectly dry, and fill it with mercury just boiled, marking the place (30) where it is stationary; then, having graduated the tube, I pour a little water or any other liquid, the subject of experiment, into it, so as to moisten the whole inside: after this I again pour in mercury, and carefully inverting the tube, exclude all air; the barometer, by standing some time, exhibits a portion of water of $\frac{1}{8}$ or $\frac{1}{10}$th of an inch, W, on the top of the mercurial column; because, being lighter, it ascends by the side of the tube, which may now be inclined, and the mercury will rise to the top, manifesting a perfect vacuum from air. I next take a cylindrical glass tube CD, open at both ends, of two inches diameter and fourteen inches in length, to each end of which a cork is adapted, perforated in the middle, so as to admit a barometer tube to be put through, and to be held fast by them; the upper cork, C, is fixed two or three inches below the top of the tube, and is one-half cut away, so as to admit water, &c., to pass by, its service being

Fig. 13.



merely to keep the tube steady. Things being thus circumstanced; water of any temperature may be poured into the wide tube, and thus made to surround the upper part or vacuum of the barometer, and the effect of temperature in the production of vapour within can be observed from the depression of the mercurial column at the top. In this way I have had water as high as 155° surrounding the vacuum; but as the higher temperatures might endanger a glass apparatus, instead of it I used the following:—

Fig. 14.



Having procured a tin tube CD, four inches in diameter and two feet long, with a circular plate soldered to one end, having a round hole in the centre, like the tube of a reflecting telescope, I got another smaller tube of the same length soldered into the larger, so as to be in the axis or centre of it; the small tube was open at both ends, and on this construction water could be poured into the large vessel to fill it, while the central tube was exposed to its temperature. Into this central tube I could insert the upper half of a syphon-barometer, and fix it by a cork, the top of the narrow tube also being corked—thus the effect of any temperature under 212° could be ascertained, the depression of the mercurial column being known by the ascent in the exterior leg of the syphon. The force of vapour from water between 80° and 212°, may also be determined by means of an air-pump, and the result exactly agrees with those determined as above."

"After repeated experiments by all those methods, and a careful comparison of the results, I was enabled to digest the following:—

## *Table of the Force of Steam from Water in the temperatures from* 32° *to* 212° (1802.)

| Temperature. | Force of Vapour in inches of Mercury. | Temperature. | Force of Vapour in inches of Mercury. | Temperature. | Force of Vapour in inches of Mercury. | Temperature. | Force of Vapour in inches of Mercury. |
|---|---|---|---|---|---|---|---|
| 32° | .200 | 78° | .940 | 123° | 3.59 | 168° | 11.54 |
| 33 | .207 | 79 | .971 | 124 | 3.69 | 169 | 11.83 |
| 34 | .214 | 80 | 1.00 | 125 | 3.79 | 170 | 12.13 |
| 35 | .221 | 81 | 1.04 | 126 | 3.89 | 171 | 12.43 |
| 36 | .229 | 82 | 1.07 | 127 | 4.00 | 172 | 12.73 |
| 37 | .237 | 83 | 1.10 | 128 | 4.11 | 173 | 13.02 |
| 38 | .245 | 84 | 1.14 | 129 | 4.22 | 174 | 13.32 |
| 39 | .254 | 85 | 1.17 | 130 | 4.34 | 175 | 13.62 |
| 40 | .263 | 86 | 1.21 | 131 | 4.47 | 176 | 13.92 |
| 41 | .273 | 87 | 1.24 | 132 | 4.60 | 177 | 14.22 |
| 42 | .283 | 88 | 1.28 | 133 | 4.73 | 178 | 14.52 |
| 43 | .294 | 89 | 1.32 | 134 | 4.86 | 179 | 14.83 |
| 44 | .305 | 90 | 1.36 | 135 | 5.00 | 180 | 15.15 |
| 45 | .316 | 91 | 1.40 | 136 | 5.14 | 181 | 15.50 |
| 46 | .328 | 92 | 1.44 | 137 | 5.29 | 182 | 15.86 |
| 47 | .339 | 93 | 1.48 | 138 | 5.44 | 183 | 16.23 |
| 48 | .351 | 94 | 1.53 | 139 | 5.59 | 184 | 16.61 |
| 49 | .363 | 95 | 1.58 | 140 | 5.74 | 185 | 17.00 |
| 50 | .375 | 96 | 1.63 | 141 | 5.90 | 186 | 17.40 |
| 51 | .388 | 97 | 1.68 | 142 | 6.05 | 187 | 17.80 |
| 52 | .401 | 98 | 1.74 | 143 | 6.21 | 188 | 18.20 |
| 53 | .415 | 99 | 1.80 | 144 | 6.37 | 189 | 18.60 |
| 54 | .429 | 100 | 1.86 | 145 | 6.53 | 190 | 19.00 |
| 55 | .443 | 101 | 1.92 | 146 | 6.70 | 191 | 19.42 |
| 56 | .458 | 102 | 1.98 | 147 | 6.87 | 192 | 19.86 |
| 57 | .474 | 103 | 2.04 | 148 | 7.05 | 193 | 20.32 |
| 58 | .490 | 104 | 2.11 | 149 | 7.23 | 194 | 20.77 |
| 59 | .507 | 105 | 2.18 | 150 | 7.42 | 195 | 21.22 |
| 60 | .524 | 106 | 2.25 | 151 | 7.61 | 196 | 21.68 |
| 61 | .542 | 107 | 2.32 | 152 | 7.81 | 197 | 22.13 |
| 62 | .560 | 108 | 2.39 | 153 | 8.01 | 198 | 22.69 |
| 63 | .578 | 109 | 2.46 | 154 | 8.20 | 199 | 23.16 |
| 64 | .597 | 110 | 2.53 | 155 | 8.40 | 200 | 23.64 |
| 65 | .616 | 111 | 2.60 | 156 | 8.60 | 201 | 24.12 |
| 66 | .635 | 112 | 2.68 | 157 | 8.81 | 202 | 24.51 |
| 67 | .655 | 113 | 2.76 | 158 | 9.02 | 203 | 25,10 |
| 68 | .676 | 114 | 2.84 | 159 | 9.24 | 204 | 25.61 |
| 69 | .698 | 115 | 2.92 | 160 | 9.46 | 205 | 26.13 |
| 70 | .721 | 116 | 3.00 | 161 | 9.68 | 206 | 26.66 |
| 71 | .745 | 117 | 3.08 | 162 | 9.91 | 207 | 27.20 |
| 72 | .770 | 118 | 3.16 | 163 | 10.15 | 208 | 27.74 |
| 73 | .796 | 119 | 3.25 | 164 | 10.41 | 209 | 28.29 |
| 74 | .823 | 120 | 3.33 | 165 | 10.68 | 210 | 28.84 |
| 75 | .851 | 121 | 3.42 | 166 | 10.96 | 211 | 29.41 |
| 76 | .880 | 122 | 3.50 | 167 | 11.25 | 212 | 30.00 |
| 77 | .910 | | | | | | |

Dr Dalton afterwards resumed the experimental examination of this subject, and was induced to modify these numbers slightly, as will be seen from our final table.

30. Passing over the experiments of Schmidt, Goldner, and others, as presenting no important differences from some of these we have already noticed, we come to those of Dr Ure, published in the *Philosophical Transactions* of 1818, and made at Glasgow during 1817. The adjoining figures represent his apparatus.

Fig. 15.

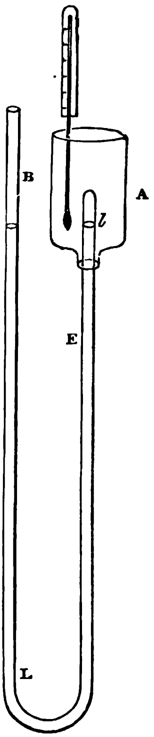


Fig. 15. represents the construction used for temperatures under and a little above the boiling point. Figs. 16. and 17. are those used for higher temperatures, the last being the more convenient of the two; each was suspended from a lofty window cieling, and placed in a truly vertical position, by means of a plumb line. Dr Ure gives the following account of his mode of experimenting. "One simple principle pervades the whole train of experiments —which is, that the progressive increase of elastic force developed by heat from the liquid incumbent on the mercury at L $l'$, is measured by the length of column which must be *added* over L, the primitive level below, in order to restore the quicksilver to its primitive level above, at *l*. These two stations or points of departure are nicely defined by a ring of fine platina wire, twisted firmly round the tube.

" At the commencement of the experiment, after the liquid, well freed from air, has been let up, the quicksilver is made a tangent to the edge of the upper ring, by cautiously pouring mercury, in a slender stream, into the open leg of the syphon B, the level ring below is then carefully adjusted.

"From the mode of conducting my experiments, there remained always a quantity of liquid in contact with the vapour, a circumstance essential to accuracy in this research.

"Suppose the temperature of the water or the oil in A to be 32° Fahrenheit, as denoted by a delicate thermometer, or by the liquefaction of ice; communicate heat to the cylinder A, by means of two argand flames, playing gently on its shoulder at each side. When the thermometer indicates 42°, modify the flames, or remove them so as to maintain a uniform temperature for a few minutes. A film or line of light will now be perceived between the mercury and the ring at *l*, as is seen under the vernier of a mountain barometer, when it is raised a few feet off the ground; were the tube at *l* and L, of equal area, or were the relation of the areas experimentally determined, then the rise of the quicksilver above L would be one-half, or a known submultiple of the total depression, equivalent to the additional elasticity of the vapour at 42° above that at 32°. Since the depressions, however, for 30 or 40° in this part of the scale are exceedingly small, one-half of the quantity can scarcely be ascertained with suitable precision, even after taking the above precautions; and besides, the other sources of error, or at least embarrassment, from the inequalities of the tube, and from the lengthening space occupied by the vapour, as the temperature ascends, render this method of reduction very ineligible.

"By the other plan we avoid all these evils; for whatever additional elasticity may be communicated to the vapour above *l*, it will be faithfully represented and measured by the mercurial column, which we must add over L, in order to overcome it and restore the quicksilver under *l*, to its zero or initial level, when the platina ring becomes once more a tangent to the mercury. At E, a piece of cork is fixed between the parallel legs of the syphon to sustain it, and to serve as a point by which the whole is steadily suspended. For temperatures above the boiling point, the part of the syphon under E is evidently superfluous, merely containing in its two legs a useless weight of equipoised mercury. Accordingly, for high heats, the apparatus, Figs. 16 or 17, is employed; and the same method of procedure is adopted: the aperture at O, Fig. 17, admits the bulb of the thermometer, which rests as usual on *l'*. The recurved part of the tube is filled with mercury, and then a little liquid is passed through it to the sealed end. Heat is now applied by an argand flame to the bottom of C, which is filled with oil or water, and the temperature is kept steadily at 212° for some minutes. Then a few drops of quicksilver may be required to be added to D',

Fig. 16.

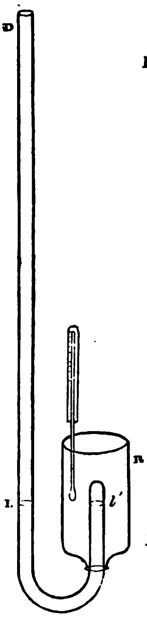
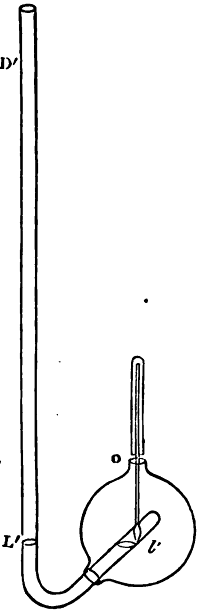


Fig. 17.



till L and *l'* be in the same horizontal plane. The further conduct of the experiment differs in no respect from what has been already described—the liquid in C is progressively heated, and at each stage mercury is progressively added over L to restore the initial level or volume at *l'*, by equipoising the progressive elasticity. The column above L being measured, represents the succession of elastic forces: when this column is wished to extend very high, the vertical tube requires to be placed for support in the groove of a long wooden prism.

"The height of the column in some of my experiments being nearly twelve feet, it became necessary to employ a ladder to reach its top. I found it to be convenient, in this case, after observing that the column of vapour had attained its primitive magnitude, to note down the temperature with the altitude of the column, then immediately to pour in a measured quantity of mercury nearly equal to three vertical inches, and to wait till the slow progress of the heating again brought the vapour in equilibrio with this new pressure, which at first had pushed the mercury within the platina ring at *l*. When the lower surface of the mercury was again a tangent to this ring, the temperature and altitude were both instantly observed.

"This mode of conducting the process will account for the experimental temperatures being very often odd and fractional numbers. I present them to the public, as they were recorded on the instant in that particular repetition of the experiment which I consider most entitled to confidence. To trim and fashion the results into an orderly looking series, would have been an easy task; but, in my opinion, this is a species of deception very injurious to the cause of science, and a deviation from the rigid truth of observation, which ought never to be made for any hypothesis: we shall afterwards have ample opportunities of exposing the fallacy of such premature geometrical refinements.

" The thermometers were constructed by Creighton with his well-known nicety, and the divisions were read off with a lens, so that $\frac{1}{10}$th of a degree could be distinguished. After bestowing the utmost pains in repeating the experiments, during a period of nearly two months, I found that the only way of removing the little discrepancies which crept in between contiguous measures, was to adopt the astronomical plan of multiplying observations, and deducing truth from the mean. It is essential, to heat with extreme slowness and circumspection the vessels A, B, C. One repetition of the experiment occupies on an average seven hours.

" The apparatus employed in obtaining these results has the peculiar advantage, over all others, that the mercurial column is never heated. It is the concurrent opinion of all chemical philosophers, that caloric travels downwards in liquids with extreme slowness and difficulty. Indeed Count Rumford's experiments led him to infer, that heat could not descend in fluids at all.

" It is evident that, in my constructions, figures 15, 16 17, only that small portion of quicksilver within the vessels A, B, and C, will be affected by the heat, but the measuring column is beyond the reach of its influence."

31. A series of experiments on high-pressure steam was subsequently made by Mr Philip Taylor, but he has not described his apparatus. A similar series was also made by Professor Arsberger of Vienna. As their results may

be useful for comparison, we have united them in the table, page 68.

*The Elastic Force of the Vapour of Water in inches of Mercury, obtained from Experiments by Dr Ure.*

| Temp. | Force. | Temp. | Force. | Temp. | Force. |
|---|---|---|---|---|---|
| 24° | 0·170 | 195° | 21·100 | 270° | 86·300 |
| 32 | 0·200 | 200 | 23·600 | 271·2 | 88 000 |
| 40 | 0·250 | 205 | 25·900 | 273·7 | 91·200 |
| 50 | 0·360 | 210 | 28·880 | 275 | 93·480 |
| 55 | 0·416 | 212 | 30·000 | 275·7 | 94·600 |
| 60 | 0·516 | 216·6 | 33·400 | 277·9 | 97·800 |
| 65 | 0·630 | 220 | 35·540 | 279.5 | 101·600 |
| 70 | 0·726 | 221.6 | 36·700 | 280 | 101·900 |
| 75 | 0·860 | 225 | 39 110 | 281·8 | 104·400 |
| 80 | 1·010 | 226·3 | 40·100 | 283·8 | 107·700 |
| 85 | 1·170 | 230 | 43·100 | 285·2 | 112·200 |
| 90 | 1·360 | 230·5 | 43·500 | 287·2 | 114·800 |
| 95 | 1·640 | 234·5 | 46·800 | 289 | 118·200 |
| 100 | 1·860 | 235 | 47·220 | 290 | 120·150 |
| 105 | 2·100 | 238·5 | 50·300 | 292·3 | 123·100 |
| 110 | 2·456 | 240 | 51·700 | 294 | 126·700 |
| 115 | 2·820 | 242 | 53·600 | 295·6 | 130·400 |
| 120 | 3·300 | 245 | 56·340 | 295 | 129·000 |
| 125 | 3·830 | 245·8 | 57·100 | 297·1 | 133·900 |
| 130 | 4·366 | 248·5 | 60·400 | 298·8 | 137·400 |
| 135 | 5·070 | 250 | 61·900 | 300 | 139·700 |
| 140 | 5·770 | 251·6 | 63·500 | 300·6 | 140·900 |
| 145 | 6·600 | 254·5 | 66·700 | 302 | 144·300 |
| 150 | 7·530 | 255 | 67.250 | 303·8 | 147·700 |
| 155 | 8·500 | 257·5 | 69·800 | 305 | 150·560 |
| 160 | 9·600 | 260 | 72·300 | 306·8 | 154·400 |
| 165 | 10·800 | 260·4 | 72·800 | 308 | 157·700 |
| 170 | 12·050 | 262·8 | 75·900 | 310 | 161·300 |
| 175 | 13·550 | 264·9 | 77·900 | 311·4 | 164·800 |
| 180 | 15·160 | 265 | 78·040 | 312 | 167·000 |
| 185 | 16·900 | 267 | 81·900 | | |
| 190 | 19·000 | 269 | 84·900 | 312 | 165·500 |

## *Taylor's and Arsberger's Experiments on High-Pressure Steam.*

| Temperature. | Taylor. | Arsberger. |
|---|---|---|
| 212° | 30·0 | „ |
| 220 | 34·9 | „ |
| 230 | 41·5 | „ |
| 232 | „ | 44·4 |
| 240 | 50·0 | „ |
| 249 | „ | 59·1 |
| 250 | 59·1 | „ |
| 260 | 70·1 | „ |
| 270 | 82·5 | „ |
| 274 | „ | 88·9 |
| 280 | 97·7 | „ |
| 290 | 114·5 | „ |
| 293·4 | 120·4 | „ |
| 300 | 133·7 | „ |
| 320 | 179·4 | „ |
| 322 | „ | 176·0 |
| 372 | „ | 325·0 |
| 432 | „ | 620·0 |

32. We now come to the most imposing series of experiments hitherto conducted. In 1823, the government of France having resolved to legislate on the means for obtaining security in the use of steam-engines, consulted the Academy of Sciences, upon the mode of most effectually promoting the public safety, without placing useless restraints on commercial enterprise and manufacturing industry. The examination into the state of knowledge concerning the phenomena of vapour at elevated temperatures, which resulted from this application, having brought the imperfections of this part of science prominently into notice, the Academy were induced to undertake a long and laborious enquiry, not entirely free from personal danger,

into the law connecting temperature with the pressure of steam. The commission consisted of the illustrious members of the Academy, Baron de Prony, Arago, Girard, and Dulong; and the results of their investigation, finished in 1829, are given in the tenth volume of the Memoirs of the Academy of Sciences, printed in 1831. These experiments, conducted principally by the MM. Arago and Dulong, were on a scale of magnitude and expense suited to the munificence of the French government and the resources of the Academy. The precautions adopted to ensure minute accuracy, entitle them to confidence, no less

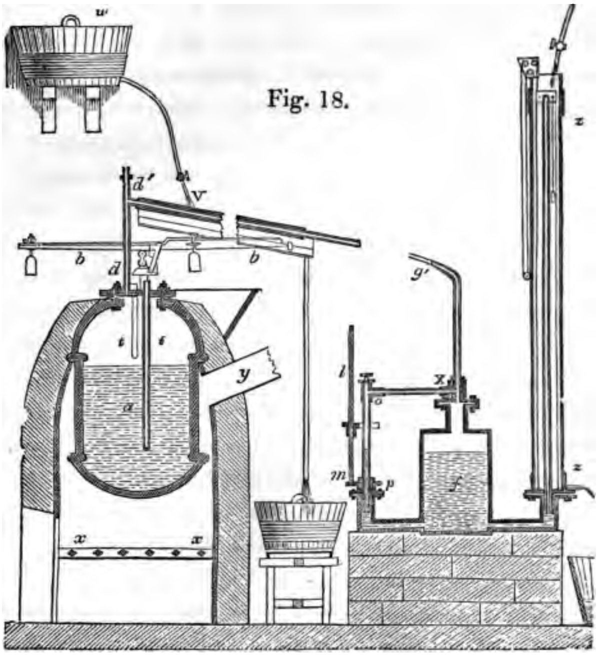


Fig. 18.

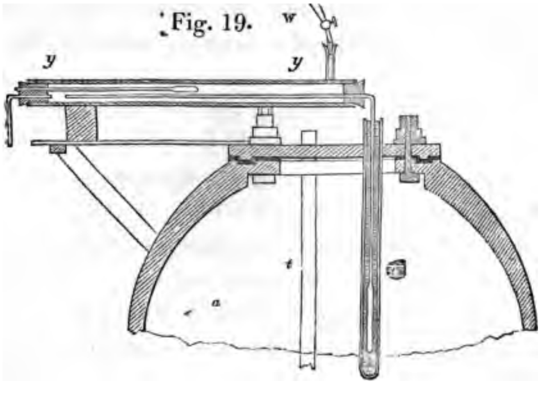
than the names of two philosophers, so well versed in experiments of a similar nature. They were carried as high as to the twenty-fourth atmosphere of pressure.

The experiments were made in one of the courts of the Observatory. Fig. 18 represents a section of the principal portions of the apparatus. The boiler *a* consists of a cylindrical body, having its axis vertical; the two ends forming top and bottom are spherical segments, strongly riveted to the body, the whole being made of the finest plate iron. The material of the cylindrical part is half an inch thick, the top and bottom being considerably thicker. The aperture at the top, six inches in diameter, was closed by a plate of wrought iron, an inch and three-quarters thick, overlapping the hole about two inches all round, and having on its lower surface a projecting ring, adapting it to a groove on the upper side of the top of the boiler: between these two surfaces was interposed a thick ring of lead, and the cover was then strongly screwed down by six steel bolts, the nuts of which had head-washers, so that, on screwing the whole together, the cover became hermetically closed. This experimental boiler was built in a furnace of considerable size and mass, intended to produce a temperature of the requisite constancy; *x x* are bars upon which the fire rests; *y* is the flue leading to the chimney.

The other parts of the apparatus connected with the boiler are *b b*, a lever, safety-valve, and weights; *y y* (fig. 19) the thermometer scales; and *w w* reservoirs of cold water, for maintaining uniform temperatures on the vertical parts of the instruments.

During the process of proving the boiler by a hydraulic pump, the common safety-valve, when used as an instrument for measuring with precision the pressure of the fluid in the boiler, was observed to give very erroneous indications, and the necessity of a more delicate apparatus was demonstrated. The improved index of pressure, made use of in the experiments, is shown in fig. 18. For measuring the great pressures to be used, a tube of mercury, 80 feet high, would have been requisite; but there was used, as a substitute for it, a glass tube *z z*, closed at the upper end, filled with dry atmospheric air, and having a length of only five feet seven inches, and an internal diameter of $\frac{1}{5}$ of an inch, and of a thickness nearly equal to its diameter. It was so arranged as to furnish a convenient manometer, capable of giving the same indications, by the contraction of the contained air, as would have been given in similar circumstances, by a column of mercury of the height due to the diminished volume of the air. The graduation of this manometer, however, presented new difficulties.

Fig. 19.



These difficulties were successfully encountered by the skill and ardour of the academicians. Every one knows that it is impossible to obtain a glass tube of considerable length and magnitude which shall have a tolerably cylindrical interior; and that there are a number of practical difficulties, which render it impossible to obtain even such a tube as that of a common thermometer, which shall possess the uniformity necessary to a good instrument. To make the proper allowance for this inevitable imperfection, the academicians easily might have adopted the same method as that used in the case of thermometer tubes, by determining the volume of successive small portions of its interior; but even this would have furnished a very partial remedy for the evil, because it had not been ascertained that the space occupied by the air in the manometer would diminish in bulk exactly in the proportion of the increase of compressing force, or of the corresponding increase in the height of the equivalent column of mercury. Two problems were therefore to be resolved at once, the elimination of the error of the tube, and the determination of the elasticity of air under high pressures. Both of them were satisfactorily accomplished, by the following laborious research.

As a preliminary measure, it was resolved to graduate the manometer, and determine the law of the elastic force of air under high pressures, by direct comparison with a column of mercury, from 75 to 80 feet in height. Such an experiment required a suitable *locale* and a stupendous apparatus. Among the buildings of the Royal College of Henri Quatre, there may be observed an old square tower, sole relic of the ancient church of Sainte Genevieve: there exist still in the interior three vaulted floors, pierced in the centre, and affording the very supports that were required for the erection of this stupendous mercurial gauge. In the centre of this opening there was raised a squared tree of the required height, and to this it was determined to attach the glass tube of 80 feet in height. To form a single glass tube of so great a length was impossible: its own weight, when constructed, under the pressure of the mercury, would have endangered its existence. The glass column was built of separate portions, united in mastic, with great care, in viroles of steel. Each portion of tube was suspended in the air by an exact counterpoise, acting over pulleys fixed to the tree; and the whole of the parts were so united in equilibrio, that each sustained only its own weight, and the pressure of the mercury due to the height of the superior portion of the column. A homogeneous metallic scale was attached, and its divisions read by a vernier, as in the common barometer.

The manometer to be graduated, and this column of mercury, were both connected by tubes with a strong cylindrical vase *f*, holding about 100 lbs. of mercury. When thus placed in communication, a column of water was forced into the vase above the mercury by a hydraulic pump, and the pressure thus produced raised the metal with equal force up into the glass-tube column on the one hand, and into the manometric tube on the other. The point to which the air was compressed was read off by a vernier, and the corresponding height of the mercury having been determined, it was manifest that the same degree of compression of the less instrument would ever after serve as the index of an equivalent column of mercury. In this manner the whole tube was graduated by careful experiment. The result of this graduation was satisfactory and very instructive. In forming the scale of the manometer, no room was left for errors of practical execution; and the comparison of the volume of the air with the height of the mercurial column demonstrated the diminution of the volume of the air to be precisely in the ratio of the pressure, so that the law of Marriotte is rigidly correct, even when extended to the extreme case where the air is reduced to less than $\frac{1}{25}$ part of its usual volume.

This preliminary process having been successfully terminated, the enormous column of glass was now laid aside, and the manometer, with its reservoir of mercury, transported to the court of the Observatory, for the purpose of being attached to the experimental boiler. Figure 18 shows the manometer *in situ*. An iron tube *d d′*, *g′*, composed of gun barrels welded together, connects the cover of the boiler *a*, with the reservoir of the manometer *f*, so as to conduct the pressure of the steam to the surface, which formerly had sustained the mercurial column. The vacant space above the mercury was filled with water, which, by condensation from a stream of water on the outside, was kept full to the constant height v. A column of water contained in the glass tube *z z*, and constantly replenished, preserved the column of air, and other parts of the apparatus, at a constant temperature, indicated by a thermometer. A tube *o p*, of glass, communicating with the reservoir of mercury above and below, indicates, on the scale *l*, *m*, the variation of level arising from the recession of the mercury into the manometer tube.

To ascertain the temperature of the water and steam of the boiler, it had been considered sufficient in the ruder experiments of earlier observers to insert thermometers directly into the boiler itself. Every one who has an acquaintance with these instruments knows, that any difference of pressure on the glass produces a false indication of the instruments, so that even the few inches of mercury in the instrument itself, when inverted, alter its indications, and a

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*The following Table contains the results of Thirty of the most unexceptionable Experiments :—*

| | 1. | 2. | 3. | 4. | 5. | |
|---|---|---|---|---|---|---|
| | Smaller Centigrade Thermometer. | Larger Centigrade Thermometer. | Elastic Forcemeters, in feet of Mercury at 32 degrees. | In Atmospheres of 76 degrees. | Condition of making he observations | |
| 1 | 122·97 | 123·7 | 1·62916 | 2·14 | max. | 1 |
| 2 | 132·58 | 132·82 | 2.1767 | 2·87 | a | 2 |
| 3 | 132·64 | 133·3 | 2·1816 | 2·88 | p. max. | 3 |
| 4 | 137·70 | 138·3 | 2·5386 | 3·348 | a | 4 |
| 5 | 149·54 | 149·7 | 3·4759 | 4·584 | max. | 5 |
| 6 | 151·87 | 151·9 | 3·6868 | 4·86 | a | 6 |
| 7 | 153·64 | 153·7 | 3·881 | 5·12 | a | 7 |
| 8 | 163·00 | 163·4 | 4·9383 | 6·51 | max. | 8 |
| 9 | 168·40 | 168·5 | 5·6054 | 7·391 | max. | 9 |
| 10 | 169·57 | 169·4 | 5·7737 | 7·613 | a. s. | 10 |
| 11 | 171·88 | 172·34 | 6·151 | 8·114 | a | 11 |
| 12 | 180·71 | 180·7 | 7·5001 | 9·893 | p. max. | 12 |
| 13 | 183·70 | 183·7 | 8·0352 | 10·6 | a | 13 |
| 14 | 186·80 | 187·1 | 8·6995 | 11·48 | a. s. | 14 |
| 15 | 188·30 | 188·5 | 8·840 | 11·66 | max. | 15 |
| 16 | 193·70 | 193·7 | 9·9989 | 13·19 | a | 16 |
| 17 | 198·55 | 198·5 | 11·019 | 14·53 | a. s. | 17 |
| 18 | 202·00 | 201·75 | 11·862 | 15·65 | a | 18 |
| 19 | 203·40 | 204·17 | 12·2903 | 16·21 | a. s. | 19 |
| 20 | 206·17 | 206·10 | 12·9872 | 17·13 | a | 20 |
| 21 | 206·40 | 206·8 | 13·061 | 17.23 | max. | 21 |
| 22 | 207·09 | 207·4 | 13·1276 | 17.3 | p. max. | 22 |
| 23 | 208·45 | 208·9 | 13·6843 | 18.05 | a | 23 |
| 24 | 209·10 | 209·13 | 13·769 | 18.16 | a | 24 |
| 25 | 210·47 | 210·5 | 14·0634 | 18.55 | p. max. | 25 |
| 26 | 215·07 | 215·3 | 15·4995 | 20·44 | a | 26 |
| 27 | 217·23 | 217·5 | 16 1528 | 21·31 | a | 27 |
| 28 | 218·3 | 218·4 | 16·3816 | 21·6 | p. max. | 28 |
| 29 | 220·4 | 220·8 | 17·1826 | 22·66 | a | 29 |
| 30 | 223·88 | 224·15 | 18·1894 | 23.994 | max. | 30 |

slight pressure of the finger would raise it a degree; the inaccuracy of the old method, when used under a pressure of 70 or 80 feet of mercury, or 450 pounds on every inch of the immersed surface of the instrument would have been great. The French academicians avoided this error, by immersing strong iron tubes *t t*, (figs. 18 and 19,) in the water and steam, in which the thermometers, surrounded by liquid metal, were kept in close communication with the heat of the fluids, without exposure to their force. By adopting only very slow variations of temperature, the error arising from the motion of heat was rendered insensible.

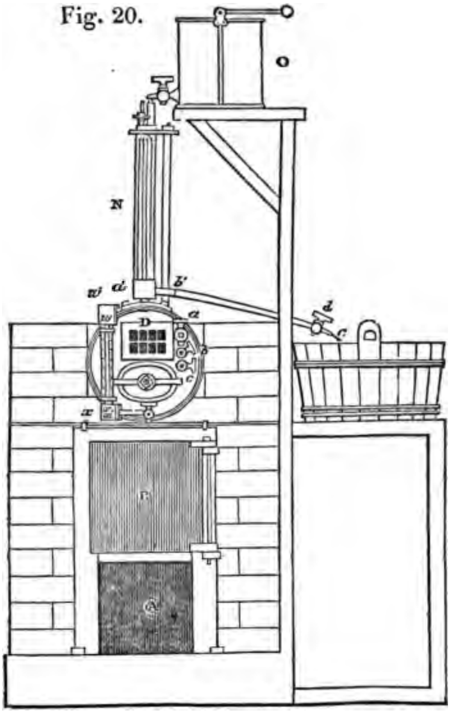
A table of temperatures, from 1 to 50 atmospheres, calculated in coincidence with the experiments of the French academicians, and adapted to English measures, is given by us in Article 57, for the purpose of convenient practical reference.

33. The latest series of experiments on the elastic force of high-pressure steam, we owe to America. At the request of the Hon. S. D. Ingham, Secretary of the Treasury of the United States, a committee of the Franklin Institute, of the State of Pennsylvania, was appointed "to examine into the causes of the explosions of the boilers used on board of steam-boats, and to devise the most effectual means of preventing the accidents, or of diminishing the extent of their injurious effects." Among other subjects, such as the strength of boilers, the construction of safety-valves, to which we shall refer in another place, this committee took into consideration the elastic force of high-pressure steam at different temperatures. Funds were placed at their disposal by the House of Representatives, and the committee consisted of such a combination

of scientific and practical men, as to give high authority to their results. On the 1st day of November 1830, the subject was placed in the hands of the following gentlemen :—Professor Alex. Dallas Bache, Mr Benjamin Reeves, Mr W. H. Keating, Mr M. W. Balwin, Mr S. V. Berrick, and Isaiah Sukens.

We shall enter more fully on the description of their apparatus of experiment than we should otherwise have done, because we shall have frequent reference to make to the whole of their experiments, not only in this article,

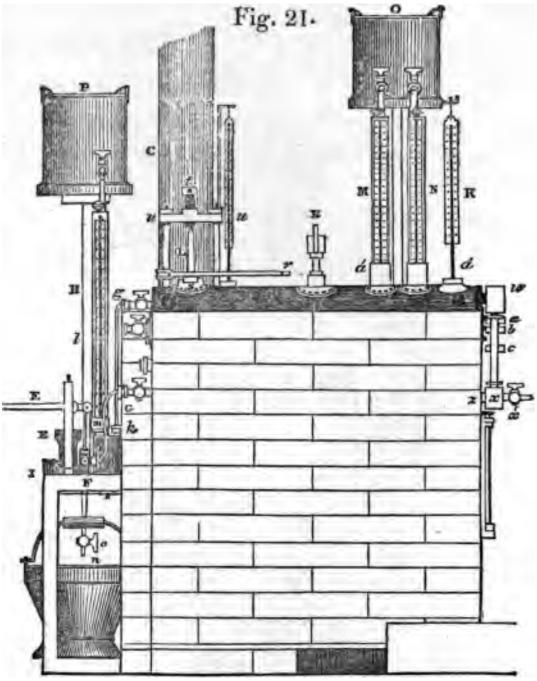
Fig. 20.



but in our article on the Steam-Engine, where we treat of explosions of boilers and their causes.

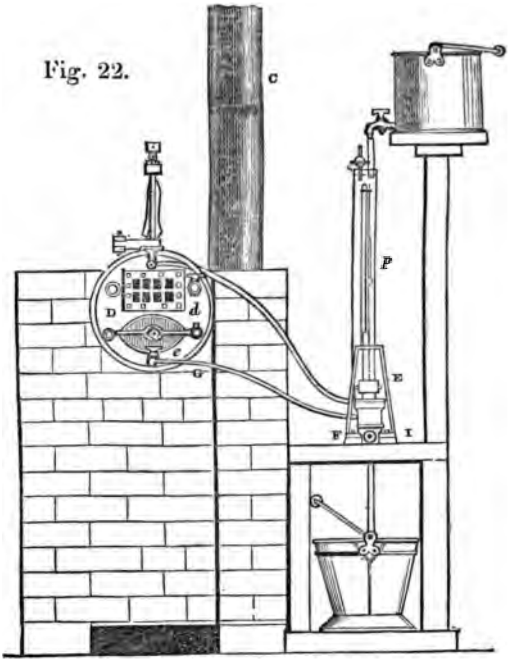
The boiler used by the committee is represented in figs. 20, 21, 22. It is a cylinder, twelve inches in

Fig. 21.



internal diameter, two feet ten inches and a quarter in length within, and a quarter of an inch thick, of rolled iron, with the ends riveted in the usual manner. Fig. 21 is a side view. Figs. 20 and 22 are end views of the boiler, and of the apparatus connected with it. The boiler was placed horizontally in a furnace, the fire surface extending about halfway round the cylinder. The furnace was arranged for a charcoal fire, the grate bars extending the whole length of the boiler, and the fire being applied nearly the whole length. The draught entered by an opening, closed in the usual manner, and left the furnace through a flue placed at one end and side of the boiler. In fig. 20, A is the ash-pit door, B the furnace door, and in 21 and 22, C is the furnace chimney.

Fig. 22.



In order to examine, readily, the interior of the boiler during the progress of the experiments, each end was provided with a glass window (D, figs. 20 and 22). The glass used was three-eighths of an inch thick. The openings in the ends, which were rectangular, were two and a half by one and three quarters inches wide.

Three gauge cocks were placed in the front end of the boiler; their positions will be particularly stated hereafter; they are shown in figs. 20 and 21, at *a*, *b*, and *c*.

To the same end, and by the side of the gauge cocks, a glass water-gauge (*w*, *x*, figs. 20 and 21) was attached, a particular description of which will be given in the detail of experiments made to compare its performance with that of the gauge cocks.

To supply the boiler with water, a forcing pump EE′ FG, figs. 21 and 22, was placed near the back end. This pump was of the ordinary construction, with a solid plunger and conical valves; the diameter of the pump was one inch, and the play of the piston one inch and three-quarters. The diameter of the pipe F G, by which the water was conveyed from the pump to the boiler, was three-hundredths of an inch. By a coupling screw, this pipe could be connected with either of the stopcocks *d e*, fig. 22, in the back end of the boiler: the opening of these cocks was two-hundredths of an inch in diameter.

To ascertain the elasticity of the steam within the boiler, a closed steam gauge (H, figs. 21 and 22), was used, a particular description of the construction, &c. of which will be given. This instrument was placed upon the same stand (I, figs. 21 and 22) which supported the pump, so that the same experimenter could observe its indications and attend to the working of the pump. The cistern of the gauge was connected, by a flexible pipe *f g*, with the upper part of the boiler.

The safety-valve is shown on the top of the boiler (K, fig.

21), midway between the ends. The graduation of it required much pains, and will receive a separate discussion.

Near the safety-valve is represented (at L, fig. 21,) the fusible plate apparatus, consisting of a sliding plate of iron, moved by a lever. On the other side of the safety-valve are the thermometers (M and N, fig. 21) plunged into iron tubes to give the temperature of the steam and water within the boiler. Above this appears the reservoir O, containing the water intended to maintain the scales of the thermometers at a constant temperature. All these parts require a more detailed description.

The steam gauge consisted of a glass tube closed at the upper, and open at the lower end, which passed steam-tight into a reservoir for mercury: when this reservoir was connected with the boiler the pressure of the steam raised the mercury into the gauge tube, compressing the air which the tube contained. The first mercurial gauge which was made, was broken by a sudden access of surcharged steam, in the experiments upon that subject, and was replaced by a second one. The method of graduation, and in general the description of the second gauge, will serve also for the first; the details only varied slightly.

The glass gauge-tube was 26.43 inches in length. To the lower end was connected an iron ferule, terminated above by a projecting ring. This ring was pressed upon the upper end of the pipe *h*, by a coupling screw, which served to form a tight juncture between the gauge and the cistern. The cistern *i* was a cylindrical vessel of cast iron, having the two projecting tubes *h* and *k*, upon which screws were cut: the first of them has been alluded to as giving a passage to the glass tube of the gauge; the second was coupled, by the pipe *f g*, to the boiler.

The gauge-tube was not of precisely equal diameter throughout, and it was judged more accurate to graduate small portions of it into equal volumes. This was done by introducing equal measures of air from the point of a sliding-rod gas measure (Hare's); this operation was performed repeatedly, and by multiple measures, to verify the results, until the marks made for the equal volumes, on a paper scale attached to the tube, coincided in the various trials. The lengths of the spaces occupied by the equal volumes were then carefully measured upon the brass scale to be used with the gauge. The slight differences between the lengths given by adjacent parts of the tube, showed that it might be considered as divided into so many small portions of uniform diameter. The mercury rising into the gauge tube from the cistern when pressure is applied, the level of the cistern is necessarily depressed; the amount of the correction for this depends upon the relation between the areas of the cistern and tube, supposed uniform. The areas of the cistern were found to be, within the limits of its use, sensibly the same; those of the tube might be so assumed for such a purpose: the ratio was therefore found by filling the gauge-tube with mercury, and pouring this into the cistern, noting the rise produced; comparing this with the mean length of the tube, the ratio of depression in the gauge for elevation in the tube was found to be as .01 to 1. The air within the tube was next carefully dried by the introduction of a receptacle of chloride of calcium, of the same length with the tube; the air having been in contact with this substance for a sufficient time, the receptacle was withdrawn through the mercury over which the drying had been effected; the tube was next placed over a dish of mercury, in the receiver of an air-pump, and the air withdrawn, until, on re-admitting air to the receiver, the mercury rose in the tube above the iron ferule.

The gauge-tube was next introduced into the cistern, the level of which, corresponding to the zero of the brass scale, was then arranged, and the point of the scale at which the mercury stood was ascertained, the barometer and thermometer being noted.

It was intended in the experiments to keep the pipe from the gauge to the boiler cool, so that it might contain water, and thus give a nearly constant pressure upon the mercury of the cistern, besides preventing the exposure of the apparatus to heat; the height of this column, above the level of the cistern, was therefore ascertained, after the gauge was put in its place by screwing the cistern *i* to the stand.

All the elements for calculating the elasticity of the steam within the boiler, from the height of the mercury of the gauge, were thus known; the temperature of the apparatus being supposed constant.

The elastic force of the steam within the boiler, together with the column of water in the steam-pipe, balances the elasticity of the compressed air within the gauge, together with the column of mercury above the level of that in the cistern. This level is not the original zero, but lower than that, by the depression produced by the rise of mercury in the gauge-tube. The depression of the mercury changes the level above which the pressure of the column of water in the steam-pipe is measured, but the change in the pressure, by the column of water, is altogether inconsiderable. The law of the elastic force of dry air, which has been recently shown, by Dulong and Arago, to be accurate, at pressures from one to fifty atmospheres, was made use of in determining the elasticity of the air in the gauge: this elasticity is inversely as the space occupied by the air. From the data already obtained, and upon the principles just stated, a table was calculated, by which the observed heights of the gauge were converted into the corresponding pressures in inches of mercury or in atmospheres. The calculations were rendered rather tedious by the unequal diameter of the bore of the tube, on account of which equal lengths did not correspond to equal volumes. The usual method of calculation was resorted to, namely, to determine, by rigid calculation, the pressures, for points sufficiently near each other, and then to interpolate for intermediate heights.

The foregoing remarks take for granted that the temperature of the air in the gauge, as well as that of the mercury, remains constant; to secure this, an arrangement was adopted similar to that employed by Dulong and Arago for the same purpose. The gauge and scale were surrounded by a glass tube *l*, cemented below into a brass cap *m*, which had an opening in the side, communicating with a discharge pipe *n*, fig. 21. The tube was attached above, by an air-tight juncture, to a tin vessel P, of considerable capacity, compared with the tube. Water being introduced into the glass tube surrounding the gauge, the flow through this tube was regulated by a stopcock *o*, placed at the end of the discharge pipe, the cistern above being filled with water.

To ascertain the temperature of the column of water surrounding the gauge, a thermometer (*p*, fig. 22) with a very small bulb, was attached to the scale at the middle of its height: by this instrument, the flow of water through the casing of the gauge was regulated so as to keep the temperature nearly constant, and any deviations from a constant temperature were ascertained and noted, that the proper correction might be applied. The correction for the expansion of the air in the gauge, by a rise in its temperature during the progress of the experiments, was made according to the rules furnished by the rate of expansion of the gases, as determined by Gay Lussac, extended to compressed air by the experiments of Davy. The correction for the changes of height of the mercurial column, within the range to which the temperature was suffered to increase, could not have been appreciable if acting entirely, and the counteracting effect of the expansion of the glass further justified its being neglected. For similar reasons no reference was made to the effects of heat on the mercury in the cistern *i*, on the cistern itself, and on the water within the pipe communicating with the boiler.

In most of the researches of the committee, refinements in the mode of using the common thermometer would have been out of place. Results which might be obtained with little additional labour, and which would be interesting in both a practical and scientific point of view, were not to be neglected, and to some of them great accuracy was essential. In the questions of the first class, the thermometers were provided with wooden scales, and were graduated by immersion up to the point at which the scale commenced, the scale and upper part of the tube being exposed to the air: this was proper, as they were intended to be immersed in mercury nearly up to the scale. These instruments were examined after coming from the maker's hands, and the instrumental error ascertained. The tubes in which the thermometers were placed, and which contained mercury, were at first placed horizontally in one of the ends of the boiler: this had the advantage of rendering the tube for indicating the temperature of the water entirely independent of the steam, and thus any difference between the temperature of one and the other might be more effectually ascertained, than when the tube giving the temperature of the water passed through the steam. The position of these instruments interfered so much with other parts of the apparatus, and so much inconvenience and danger of error was experienced from the separation of the column of mercury in the thermometer, that these tubes were not used after the first weeks of experiment, and two vertical tubes, placed as already shown, were substituted for them.

The thermometers used, when the relation between the temperature of the steam and water, and the elasticity of the steam were to be observed in conjunction with some of the subjects more directly under the cognisance of the committee, had much pains bestowed upon them.

The scales (M and N) were metallic, and surrounded by glass tubes, fitting into a cup *a′*, through the bottom of which the stem of the thermometer passed watertight; a pipe *b′ c*, fig. 20, from the side of each cup, and provided with a stopcock *d*, regulated the flow of water through the enveloping tubes: a tight connexion above with a reservoir (O) served, as in the case of the gauge, to supply the tubes with water. Small thermometers on the back of the scale of the large ones, showed the temperature of the water which surrounded them. The enveloping tubes being filled with water at 60°, the position of the boiling point of water and of the fusing point of tin, were used to verify the accuracy of graduation. The latter point, which is high upon the scale of the thermometer, having been very accurately determined, and being easily and with certainty ascertainable, serves as an excellent check upon the graduation. The greatest error within the limits just stated, was in one instrument, three-fourths of a degree, and in the other one degree of Fahrenheit. The scales were graduated from two to two degrees, one quarter of a degree being readily estimated upon them. The corrections required by this examination were made through the medium of a table prepared for the purpose. In order to call the attention to the temperature of the water surrounding the scales, this temperature was recorded from time to time, when the height of the thermometers was observed. At no time did the rise of temperature, permitted in the water, make it necessary to apply a correction for the expansion of the scale. None was required for the cooling effect of the water around the stem upon the mercury, owing to the method of verifying the scale.

The other parts of the apparatus, less general in their use, as the water-gauge, safety-valve, fusible plate apparatus, &c., will be more conveniently described in connexion with the experiments for which they were devised.

34. With this apparatus, and these precautions, a series of experiments were made, the results of which are contained in the following tables:—

The Table, No. 1, contains the temperature observed by the thermometer in the water, corrected for the error of the graduation; the temperature of the scale of the thermometer, with a view to show that it was not allowed to vary too considerably; the observed height of the mercury in the gauge, reduced to its mean height; the temperature

## TABLE, No. I.—*Of the Elastic Force of Steam at different Temperatures.*

| Temperature o. steam | Temp. of scale of thermometer. | Height of mercury in air gauge. | emperature of air in gauge | olume of air at observed temperature. | Volume of air at 48° Fahrenheit. | Elasticity o air in inche of mercury. | 1 Heigh of gauge | eight + .01 height. | eight + .01 eight —1.2 inches. | Total elasti ity in inche of mercury. | astic force in atmospheres of 30 inches. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fah.° | Fah.° | Inches. | Fah.° | Vols. | Vols. | Inches | Inches. | Inches. | Inches. | Inches. | Atmos. |
| | | 3.99* | 62 | 8.33 | 8.101 | 27.26 | .04 | 4.03 | 2.74 | 30.00 | 1.00 |
| 262¼ | 63 | 15.04 | 74 | 3.93 | 3.737 | 59.09 | .15 | 15.19 | 13.90 | 72.99 | 2.43 |
| 268½ | 71 | 16.34 | ” | 3.43 | 3.259 | 67.76 | .16 | 16.50 | 15.21 | 82.97 | 2.76 |
| 275½ | ” | 17.34 | ” | 3.05 | 2.898 | 76.20 | .17 | 17.51 | 16.22 | 92.42 | 3.08 |
| 286½ | ” | 18.94 | ” | 2.44 | 2.319 | 95.23 | .19 | 19.13 | 17.84 | 113.07 | 3.77 |
| 296½ | ” | 19.94 | ” | 2.05 | 1.948 | 113.36 | .20 | 20.14 | 18.85 | 132.21 | 4.41 |
| 298½ | 73 | 20.11 | ” | 1.99 | 1.891 | 116.76 | .20 | 20.31 | 19.02 | 135.80 | 4.53† |
| 302 | ” | 20.44 | ” | 1.86 | 1.767 | 124.98 | .20 | 20.64 | 19.35 | 144.33 | 4.81‡ |
| 305½ | 76 | 20.79 | 75 | 1.73 | 1.641 | 134.57 | .21 | 21.00 | 19.71 | 154.28 | 5.14 |
| 313¼ | 79 | 21.39 | ” | 1.50 | 1.422 | 155.30 | .21 | 21.60 | 20.31 | 175.61 | 5.85§ |
| 317¾ | 80 | 21.64 | ” | 1.405 | 1.332 | 165.79 | .22 | 21.86 | 20.57 | 186.36 | 6.21 |
| 320¾ | ” | 21.79 | 76 | 1.347 | 1.275 | 173.20 | .22 | 22.01 | 20.72 | 193.92 | 6.46 |
| 327¾ | ” | 22.24 | ” | 1.176 | 1.113 | 198.41 | .22 | 22.02 | 20.73 | 219.14 | 7.30 |
| 333¾ | ” | 22.69 | ” | 1.004 | 0.950 | 232.46 | .23 | 22.92 | 21.63 | 254.09 | 8.47 |

* This observation shows the height of the gauge before the experiment, corrected for the height of the barometer.
† Mean of four observations. ‡ Mean of two observations. § Mean of two observations.

of the air in the gauge ; its volume at the observed temperature ; the volume reduced to 48°, the temperature of graduation of the gauge at which the column of mercury equivalent to an atmosphere, is very nearly 30 inches ; the elasticity of the compressed air, in inches of mercury ; the correction in the height of the column of mercury, for the depression produced in the cistern below ; the height thus corrected ; the height, after subtracting the sensibly constant number for the column of water between the level of the steam-pipe from the boiler and the cistern of the gauge ; the total elasticity in inches of mercury ; the elasticity in atmospheres. The first line of numbers in the table is merely introduced for the convenience of presenting certain data required for subsequent calculation ; it gives the height of the mercury in the gauge before beginning the observations, after correcting for the height of the barometer.

A curve traced to represent these observations, the ordinates representing the pressures, and the abscissæ the temperatures, is quite regular, until the temperature corresponding to eight atmospheres is attained, when it rises abruptly. This fact was explained, by examining the gauge ; it was found that the cement used in attaching the glass tube to its ferule had become softened, and had permitted the tube to rise. This defect was remedied and its recurrence prevented. It was then determined to repeat the entire series of observations, and to carry them as high as could be done, with reasonable convenience, aiming particularly to embrace the range of working pressures of the American engines.

The results are contained in the following table, in which the observed data, and calculated numbers, are

## TABLE NO. II.—*Of the Elastic Force of Steam at Different Temperatures.*

| Temperature of Steam. | Temperature of thermometer scale. | Height of mercury in air gauge. | Temperature of air in gauge. | Volume of air at observed temperature. | Volume of air at 48° Fah. | Elasticity of air in inches of mercury. | .01 Height of gauge. | Height + .01 height. | Height + .01 height —1.29 inches. | Total elasticity in inches of mercury. | Elastic force in atmospheres of 30 inches. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fah.° | Fah.° | Inches. | Fah.° | Vols. | Vols. | Inches. | Inches. | Inches. | Inches. | Inches. | Atmos. |
| | | 5.56* | 48 | 7.695 | 7.695 | 25.67 | .06 | 5,84 | 4.55 | 30.00 | 1.00 |
| 248¼ | 54 | 14.04 | 53 | 4.32 | 4.277 | 46.19 | .14 | 14.18 | 12.89 | 59.08 | 1.97 |
| 269½ | — | 17.34 | 52 | 3.05 | 3.026 | 65.29 | .17 | 17.51 | 16.22 | 81.51 | 2.72 |
| 284½ | — | 19,64 | " | 2.17 | 2.152 | 91.76 | .19 | 19.83 | 18.54 | 110.30 | 3.68 |
| 289½ | — | 20,06 | " | 1.99 | 1.974 | 100.05 | .20 | 20.26 | 18.97 | 119.02 | 3.97 |
| 294½ | — | 20.56 | 53 | 1.82 | 1.802 | 109.63 | .21 | 20.77 | 19.48 | 129.11 | 4.30 |
| 299½ | — | 21.04 | 54 | 1.63 | 1.611 | 122.66 | .21 | 21.25 | 19.96 | 142.62 | 4.75 |
| 304½ | — | 21.34 | 54½ | 1.52 | 1.500 | 131.66 | .21 | 21.55 | 20.26 | 151.92 | 5.06 |
| 310¼ | — | 21.64 | " | 1.405 | 1.382 | 142.94 | .22 | 21.86 | 20.57 | 163.51 | 5.45 |
| 314¾ | 58 | 22.04 | 55 | 1.25 | 1.233 | 160.26 | .22 | 22.26 | 20.97 | 181.23 | 6.04 |
| 319¾ | — | 22.34 | 55½ | 1.14 | 1.124 | 175.86 | .22 | 22.56 | 21.27 | 197.13 | 6.57 |
| 329¾ | — | 22.84 | 56 | 0.95 | 0.937 | 210.84 | .23 | 23.07 | 21.78 | 232.62 | 7.75 |
| 334½ | 66 | 22.94 | 57 | 0.92 | 0.904 | 218.60 | .23 | 23.17 | 21.88 | 240.48 | 8.02 |
| 338¾ | — | 23.04 | 57½ | 0.887 | 0.870 | 226.92 | .23 | 23.29 | 22.00 | 248.92 | 8.30 |
| 345 | — | 23.24 | " | 0.82 | 0.805 | 245.44 | .23 | 23.47 | 22.18 | 267.62 | 8.92 |
| 348 | — | 23.34 | 58 | 0.787 | 0.771 | 256.05 | .23 | 23.57 | 22.28 | 278.33 | 9.28 |
| 350 | — | 23.44 | " | 0.752 | 0.737 | 267.97 | .23 | 23.67 | 22.38 | 290.35 | 9.68 |
| 352 | — | 23.50 | " | 0.733 | 0.719 | 274.92 | .23 | 23.73 | 22.44 | 297.36 | 9.91 |
| 346 | — | 23.28 | 62 | 0.807 | 0.785 | 251.78 | .23 | 23.51 | 22.22 | 274.00 | 9.13 |

* This observation shows the corrected height of the gauge before the experiments.

TABLE NO. III.—*Of the Elastic Force of Steam at Different Temperatures.*

| Temperature of Steam. | Temperature of thermometer scale. | Height of mercury in air gauge. | Temperature of air in gauge. | Volume of air at observed temperatures. | Volume of air at 48° Fah. | Elasticity of air in inches of mercury. | +.01 Height of gauge. | Height of gauge +.01 height. | Height +.01 height—1.29 inches. | Elasticity of steam in inches of mercury. | Elastic force in atmospheres. | No. of observations. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fah.° | Fah.° | Inches. | Fah.° | Vols. | Vols. | Inches. | Inches. | Inches. | Inches. | Inches. | Atmos. | |
| | | 3.91* | 59 | 8.35 | 8.169 | 27.34 | .04 | 3.95 | 2.66 | 30.00 | 1.00 | |
| 234 | 54 | 8.80 | 55 | 6.39 | 6.301 | 35.45 | .09 | 8.89 | 7.60 | 43.05 | 1.43 | 1 |
| 239¼ | 62 | 9.94 | 61 | 5.94 | 5.788 | 38.59 | .10 | 10.04 | 8.75 | 47.34 | 1.58 | „ |
| 245¼ | 68 | 11.16 | 63 | 5.46 | 5.300 | 42.14 | .11 | 11.27 | 9.98 | 52.12 | 1.74 | 5 |
| 250¼ | 70 | 12.54 | 63 | 4.92 | 4.776 | 46.77 | .12 | 12.66 | 11.37 | 58.14 | 1.94 | 4 |
| 256¼ | 73 | 13.88 | 64 | 4.38 | 4.243 | 52.64 | .14 | 14.02 | 12.73 | 65.37 | 2.18 | 5 |
| 262¾ | 77 | 15.14 | 64 | 3.89 | 3.768 | 59.27 | .15 | 15.99 | 14.00 | 73.27 | 2.44 | 2 |
| 271 | 70 | 16.34 | 65 | 3.43 | 3.316 | 67.35 | .16 | 16.50 | 15.21 | 82.56 | 2.75 | 4 |
| 278 | 75 | 17.44 | 70 | 3.01 | 2.882 | 77.49 | .17 | 17.61 | 16.32 | 93.81 | 3.13 | 3 |
| 288¼ | 75 | 18.74 | 68 | 2.50 | 2.403 | 92.94 | .19 | 18.93 | 17.64 | 110.58 | 3.69 | 3 |
| 291 | 76 | 19.14 | 65 | 2.36 | 2.282 | 97.88 | .19 | 19.33 | 18.04 | 115.92 | 3.86 | 2 |
| 292½ | 65 | 19.44 | 63 | 2.25 | 2.184 | 102.26 | .19 | 19.63 | 18.34 | 120.60 | 4.02 | 3 |
| 300 | 73 | 20.12 | 65 | 1.98 | 1.914 | 117.33 | .20 | 20.32 | 19.03 | 136.36 | 4.55 | 4 |
| 303½ | 74 | 20.54 | 66 | 1.82 | 1.756 | 127.27 | .20 | 20.74 | 19.45 | 146.72 | 4.89 | 1 |

* This observation shows the corrected height of the gauge before the experiments.

arranged as in Table No. I. This table extends to 9.9 atmospheres, and to the temperature of 352° Fahrenheit.

Care was taken that the elasticities were increased not too rapidly, and the last numbers obtained were verified by keeping the temperature sensibly constant for a considerable time.

There is one observation, namely, that at 329¾°, which is certainly recorded erroneously; but omitting this one, the rest which are given, present a very tolerable regularity in the curve traced to represent them. For the sake of adding to the force of these results, the scattered observations of temperatures and pressures incidentally made during the other experiments of the committee, are brought together in the annexed table, No. III.

A column is added to that table, to show the number of observations employed in obtaining the results.

Table No. III. enables us to go as low as 1.43 atmospheres, and is strikingly accordant with the two others as far as they extend in common.

A curve which would be traced by the following table, which may be considered to represent the mean of the foregoing, would differ little more than one-tenth of an atmosphere in any part of the range from the observations, omitting one noticed in the first, and another noticed in the second table; the pressures in general differing less than one-tenth of an atmosphere from the observed pressures.

To compare our results with those given by the committee of the French Academy, we have traced a curve, from the following table, and another from those of the thirty observations, selected by the committee of the Academy, from their experiments which are below ten atmospheres. The curve of our observations, passes at low pressures nearer to the axis than that of the French experimenters, and after coinciding at the medium pressures of the table, crosses the latter, differing at 10 atmospheres 5 degrees, or at 352½ degrees .65 of an atmosphere.

*Table of the Elastic Force of Steam from One to Ten Atmospheres.*

| Pressure. | Observed Temp. | Pressure. | Observed Temp. | Pressure. | Observed Temp. | Pressure. | Observed Temp. | Pressure. | Observed Temp. |
|---|---|---|---|---|---|---|---|---|---|
| Atmo. | Fah.° | Atmo. | Fah.° | Atmo. | Fah.° | Atmo. | Fah.° | Atmo. | Fah.° |
| 1 | 212 | 3 | 275 | 5 | 304½ | 7 | 326 | 9 | 345 |
| 1½ | 235 | 3½ | 284 | 5½ | 310 | 7½ | 331 | 9½ | 349 |
| 2 | 250 | 4 | 291½ | 6 | 315½ | 8 | 336 | 10 | 352½ |
| 2½ | 264 | 4½ | 298½ | 6½ | 321 | 8½ | 340½ | | |

The difference here noticed is too considerable to be admitted as within the limits of errors in the apparatus or in observation. Having an authority of so much weight against them, the committee have been driven to examine their results very closely. The care employed in the graduation of the gauge seems to exclude the idea of error from it; the upper portion of the scale was divided to .05 of an inch, and could easily be read to half of that distance, making about .1 of an atmosphere at the highest pressure attained. A specific correction for capillarity was ascertained and employed. In one point of manipulation, namely, the method employed to dry the air, the committee differed from what was usual, and though they think there is reason to confide in that method, they have examined what effect would be produced if air were saturated with moisture. Recent experiments on the passage of gases, out and into vessels placed over mercury, and observations connected with them, warrant, moreover, a suspicion, that dry air standing in a glass vessel over mercury, the surface of which is covered by water, may become impregnated with vapour. The effect of such a source of error they have calculated in the highest and lowest results of Table No. II. and find it to be as follows:—

For 248¼° the tension of the vapour is 1.96 instead of 1.97,
and 352 ... ... ... 9.78 ... 9.91.

Differing from the numbers given in Table No. II. by .01 and .13 of an atmosphere.

This supposition is thus shown to be inadequate to explain the discordance, and must, in fact, be deemed, to a certain extent, gratuitous.

The committee have next compared the results furnished by the safety-valves graduated independently of the gauge, and these, as has already been shown, gave calculated pressures four per cent and ten per cent higher than the pressures indicated by the gauge. From these independent experimental data, then, we have an evidence that our results are probably not too high.

## SECT. III.—ON THE MATHEMATICAL LAW WHICH CONNECTS THE ELASTIC FORCE OF VAPOUR WITH ITS TEMPERATURE.

* 35. An inference which may be drawn from all these experiments is, that Nature seems to affect a certain law in the dilatation of aeriform fluids by heat. They seem to

be dilatable nearly in the proportion of their present dilatation. For, if we suppose the vapours to resemble air in having their elasticity in any given temperature proportional to their density, we must suppose that if steam of the elasticity 60, that is, under a pressure of 60 inches of mercury, were subjected to a pressure of 30 inches, it would expand into twice its present bulk. The augmentation of elasticity, therefore, is the measure of the bulk into which it would expand, in order to acquire its former elasticity. Taking the increase of elasticity, as a measure of the bulk into which it would expand under one constant pressure, we see that equal increments of temperature produce nearly equal multiplications of bulk. Thus, if a certain diminution of temperature diminishes the bulk of steam $\frac{1}{4}$, another equal diminution will very nearly diminish this new bulk $\frac{1}{4}$. Thus, in our experiments (Art. 25), *the temperatures being in arithmetical progression, having equal differences, we see that the corresponding elasticities are very nearly in the continued proportion of* 1 to 2, *thus :*

| Temperatures | 110° | 140° | 170° | 200° | 230° |
|---|---|---|---|---|---|
| Corresponding Elasticities. | 2.25 | 5.15 | 11.05 | 22.62 | 44.7. |

Now, although extreme temperatures differ considerably from this law, still we see that there is a considerable approximation to it; and it will frequently assist us, to recollect that within these limits an increase of 30° of temperature nearly doubles the elasticity and bulk of watery vapour.

This law obtains exactly in air and other gases, all of which are subject to the Boylean law, or law of Marriotte, as it is called, and have their elasticity proportional to their bulk inversely. If the bulk were always augmented in the same proportion by equal augmentations of temperature, the elasticities would be accurately represented by the ordinates of a logarithmic curve, of which the temperatures are the corresponding abscissæ; and we might contrive such a scale for our thermometer, that the temperatures would be the common logarithms of the elasticities, or of the bulks having equal elasticity; or, with our present scale, we may find such a multiplier $m$, for the number $t$ degrees of our thermometer (above the temperature where the elasticity is equal to unity), that this multiple shall be the common logarithm of the elasticity F; so that

$$\text{Log. } F = m\,t \text{ .............. A.}$$

36. As Dr Dalton was one of the earliest to investigate the properties of steam by well-contrived experiment, he has likewise been the most successful in obtaining profound and accurate views of those general relations which connect this with co-ordinate branches of physical knowledge. His experimental researches have been the model of imitation to all subsequent investigators. His apparatus was simple, his artifices were highly refined, and his processes elegant and precise; and, consequently, the results of his labour were immediately transferred to the works of highest philosophical character on the Continent and at home, and became part of the staple of accurate science. But his philosophical views were not so readily and widely received, and the fault lay, in part, with their author himself. He had overreached the existing condition of the other branches of contemporaneous science; and in taking for granted the accuracy of the existing state of knowledge, he proceeded to raise a theo-

retical structure on ground not yet sufficiently ascertained and determined. The result has been, as might have been anticipated, that now, when the progress of accurate knowledge has altered the conditions on which his system was based, his theory, becoming inapplicable to the facts, has been thrown aside, and, instead of having been modified, as it ought to have been, in conformity with the advancement of science, it has been hastily abandoned or undeservedly neglected.

From an extensive and laborious review of all that has since been added to the stores of our experimental facts on the properties of vapour, we have been conducted to this conclusion, that of all the views that have been taken of the constitution and laws of vapour, Dr Dalton's are those from which we may gain the clearest and most adequate conceptions; and therefore we have undertaken the task of reviewing the subject, and of making those changes and modifications which are now required to represent with fidelity and precision the advanced state of our knowledge.

If we examine any series of even the earlier experiments on the vapour of water (such as those in Art. 27), we cannot fail to recognise a certain degree of regularity in the progress of the increasing force of the vapour as the temperature is successively augmented. At the temperature of freezing water, the force of its vapour being taken at two-tenths of an inch, we see that it becomes more than *doubled* by raising the temperature 22½° : this again is rather more than *doubled* at 22½° of additional heat; and this is again exactly *doubled* by a third addition of 22½°. But another addition of 22½° of heat scarcely doubles the pressure; and 22½° more fall still further short of producing that effect; so that, while the increase of the force of the steam takes place rapidly, with equal additions of heat, the rapidity of the increase does not maintain a constant proportion, but slowly diminishes as the temperature ascends. This will be plainer in the following table:—

| Temperature of the Vapour. | Pressure on Mercury. | Proportion of Increase. | Decrease of Proportion. |
|---|---|---|---|
| 32° | 0·200 | $2 + \frac{17}{100}$ | |
| 54½ | 0·445 | | 8· |
| 77 | 0·910 | $2 + \frac{9}{100}$ | |
| 99½ | 1·820 | $2 + \frac{0}{0}$ | 9· |
| 122 | 3·500 | $2 - \frac{8}{100}$ | 8· |
| 144½ | 6·450 | $2 - \frac{16}{100}$ | 8· |
| 167 | 11·250 | $2 - \frac{25}{100}$ | 9· |
| 189½ | 18·800 | $2 - \frac{23}{100}$ | 8· |
| 212 | 30·000 | $2 - \frac{41}{100}$ | 8· |

From this simple collocation of results, a principle of progression is manifested. The number of degrees in the first column increases at each step by 22½ degrees, and the number in the second column on the same line is nearly doubled every step. At first, as the third column shows, it is more than doubled by $\frac{17}{100}$, next time it is more than doubled by $\frac{9}{100}$, and next it is doubled exactly; after this, however, it falls $\frac{8}{100}$ short of being doubled, next time by twice that quantity, and so on, till we find at last that it falls short of doubling every time by about 8 or 9 hundredths for every 11½ degrees. Although, therefore, we may at first be disappointed in finding that the reduplication does not proceed with the regularity of a law of nature, still it is satisfactory to know that the deviation from this progression is itself the subject of a tolerably simple law, so as to enable us to predict, with some measure of accuracy, what would take place if we were to add another increment of 22½ degrees. We should then diminish the number in the third column by $\frac{9}{100}$, and by doubling the pressure, and having regard to this diminution from the preceding numbers, $2 - \frac{41}{100}$ we should have at

$234\frac{1}{2}°$ 45.00 $2.-\frac{50}{200}$ —9

And again at

257 63.90 $2.-\frac{58}{100}$ —8

It was in this way that Dr Dalton examined his experiments, and proceeded to form his tables, so as to include not only those points which he had already examined by experiment, but to fill up the vacancies, and extend them beyond the range which his actual observation had reached. He thus completed the table which we have already given. This was much more accurate than any previous table, and, being more extensive, formed a valuable addition to our knowledge.

This simple method of interpolation by which Dr Dalton constructed his table, although it suited perfectly the limited object which he at that time had in view, and coincided with the limited range of his observations, was not of a sufficiently general description to stretch far beyond that sphere. It is obvious, that if his progression were continued much further, it would come to an end of itself; because the constant diminution of the proportion in the third column would bring it down to nothing, and so the march of the method would close and retrograde, and would thus bring the method of the formation into opposition with the march of the fact, for the force of the vapour continues to increase. Dr Dalton was himself the first to recognise the limited applicability of his method of interpolation to wide ranges of temperature; and, accordingly, in his lectures on heat, delivered at Edinburgh and Glasgow in 1807, and in his *New System of Chemistry*, published in 1808, he developed those larger and more matured views which had grown up in his mind during a longer and more thorough investigation of the subject.

It does not belong to this article to consider the nature, and decide on the merits of Dr Dalton's theory of temperature; nor is a perfect acquaintance with that theory of any further use in understanding his views of the constitution of vapour, than to enable us to perceive how he was led from the former to the latter. For the validity of his views regarding steam, it is indeed of no consequence whether the theory of temperature from which it was originally deduced, be true or erroneous. The general laws which he has determined for elastic vapours, form the well-settled foundation on which any theory of temperature, true or false, must in some measure ultimately rest.

The only circumstances in regard to temperature which it is proper to keep in view, are these: that the present thermometer used to indicate temperature is not to be regarded as an exact measure of the *quantity* of heat producing that temperature. This is shown from the circumstance, that the same quantity of fuel which heats water 10° from 180° to 190°, will not heat it from 80° to 90°, an equal interval. From considerations of this nature it was evident that the divisions of the common scale were too large near the bottom, and too small in the higher portions; and Dr Dalton evinced this difference to be so great, that 72° of the common scale below the freezing point of water down to the freezing point of mercury, were to be reckoned as equivalent to as many as 207° of Dalton's scale. Proceeding on this view, it was necessary to find the ratio of these two series of indications, the indications of Dalton's and of Fahrenheit's scale; and he accordingly found that the progression of Fahrenheit's scale was in a high geometrical proportion to the increments of true temperature of the new one. On this principle he proceeded to construct his new scale of temperature, of which the following is a specimen:—

| Fahrenheit's Scale. | | Dalton's Scale. |
|---|---|---|
| —40° | (Freezing point of Mercury),……. | —175° |
| 32 | (Freezing point of water),……….. | + 32 |
| 110 | (Middle of scale),…………………… | 122 |
| 212 | (Boiling point of water),…………… | 212 |
| 296 | ………………………………… | 272 |
| 342.7 | ………………………………… | 302 |
| 409.8 | ………………………………… | 342 |
| 520.3 | ………………………………… | 402 |
| 600.7 | ………………………………… | 422 |

By this new scale of temperature it was found that many of the apparent anomalies in the effects of heat were resolved, and the complex relations of its phenomena rendered very simple. Amongst others, the most important were the phenomena of vapours, as it was found that, on the new scale of temperature, the elastic force of different vapours increased almost exactly in a uniform ratio to equal increments of heat.

But the further progress of experimental science soon raised up serious grounds of objection to this view. It was found that Dr Dalton had rated the inaccuracies of the present scale somewhat too high. His results were thus rendered inapplicable to the advanced state of some branches of thermal science; and his theory, instead of being modified and improved, was first hastily discredited and then summarily dismissed. Unable to follow the theory to its whole extent, it was abandoned even when it had furnished a safe guide thoroughly to explicate the intricacies of obscure truth.

It is now, therefore, necessary to examine the views of those who have endeavoured to form adequate representations of the mathematical law which connects the elastic force of vapour with its temperature. We shall first of all examine the methods and views which they have adopted, and then consider whether there may not be deduced from the clear theoretical views of Dr Dalton, tested and modified by the results of modern experiment, mathematical expressions of a character, at once less empirical, and more closely in accordance with observed phenomena.

37. M. de Prony was the first to represent, by a purely empirical formula, the law which governs the relation between the temperature and the elasticity of aqueous vapour. It was derived by him, in 1796, from the experiments of M. de Betancourt, and constructed according to a method of interpolation, which he afterwards presented to the Academy of Sciences, and which they have placed among the *Mémoires des Savans Etrangers*.

The Formula which he has thus obtained is

$$y = e^{\mu+\lambda x} - e^{\mu'+\lambda' x} - e^{\sigma x-\rho} + e^{\sigma' x-\rho'};$$

$y$ being the height of the mercurial column of pressure.
$x$ the temperature.

$e$ the base of the common log. . . $=10.$

$\mu$ an empirical co-efficient, . . . $=0.068831$

$\lambda$ . . . . . . . . . $=0.019438$

$\lambda'$ . . . . . . . . . $=0.013490$

$\sigma$ . . . . . . . . . $=0.058576$

$\sigma'$ . . . . . . . . . $=0.049157$

$\rho$ . . . . . . . . . $=4.686080$

$\rho'$ . . . . . . . . . $=3.932560$

The same formula holds in the case of alcoholic vapour, the numerical co-efficients being changed, and a constant quantity $A=1.126447$ subtracted from the result.

$\mu=-0.04853,\ \lambda=0.02393,\ \sigma=0.0467,\ \rho=2.60249$

$\mu'=-0.63414,\ \lambda'=0.09653,\ \sigma'=0.0294,\ \rho'=1.64909$

This formula was afterwards improved by its author, and presented in the following more elegant and convenient shape.

$$z=\mu_{,}\,\rho_{,}^{x}+\mu_{,,}\,\rho_{,,}^{x}+\mu_{,,,}\,\rho_{,,,}^{x}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ \mathrm{B.}$$

Where $z$ is the mercurial column of pressure, $x$ the temperature centigrade, and $\mu_{,}\ \mu_{,,}\ \mu_{,,,}\ \rho_{,}\ \rho_{,,}\ \rho_{,,,}$ equidistant constants derived from experiment.—For water, these values are:—

$\mu_{,}=-0.0000000196$ $\rho_{,}=1.136006$

$\mu_{,,}=+0.023403$ $\rho_{,,}=1.038037$

$\mu_{,,,}=-0.023403$ $\rho_{,,,}=1.022490$

and hence he has formed the numbers which we have united in a subsequent table.

M. de Prony's formula for the vapour of alcohol is—

$$z = \mu_{\prime}\,\rho_{\prime}{}_{x} + \mu_{\prime\prime}\,\rho_{\prime\prime}^{x} + \mu_{\prime\prime\prime}\,\rho_{\prime\prime\prime}^{x} + \mu_{\prime\prime\prime\prime};$$

the constants being

$$\mu_{\prime} = -0.000058 \qquad \rho_{\prime} = 1.090391$$

$$\mu_{\prime\prime} = +0.024669 \qquad \rho_{\prime\prime} = 1.045453$$

$$\mu_{\prime\prime\prime} = +0.005677 \qquad \rho_{\prime\prime\prime} = 0.836030$$

$$\mu_{\prime\prime\prime\prime} = -\left(\mu_{\prime} + \mu_{\prime\prime} + \mu_{\prime\prime\prime}\right)$$

$$= -0.030288$$

These numbers refer to the centigrade thermometer, and to an atmosphere of 0.7577 metres in height.

These formulæ indicate some singular phenomena at high temperatures, which have not been observed in recent experiments, and may therefore be deemed anomalies of the formulæ themselves rather than the legitimate results of the experiments they were intended to represent. The formulæ are, besides, much too operose to be useful.

38. The experiments of Dr Dalton are adopted by Laplace in the fourth volume of the *Méchanique Céleste*, where we find him applying them to the calculation of the influence of the aqueous vapour of the atmosphere upon astronomical refractions. As an empirical formula agreeing sufficiently with Dr Dalton's experiments, he adopted the following approximation:—

$$f_n = p.\,(10)^{n.0.0154547 - n^2.0.0000625826} \quad \ldots\ldots\ldots \text{C.}$$

$f$ being the force at any temperature $n$ of the centesimal scale, reckoned from the point of ebullition, and $p$ the pressure of the atmosphere $=0.76$ metres; or that we have only to add to the log. of 0.76 the quantity $n$ .0.0154547 —$n^2$ .0.0000625826 and we have the log. of the common tabular logarithm of the corresponding elasticity at $n$ centesimal degrees of temperature.—*Méch. Cél.* iv. 273.

These numbers agree very well with the observations they were intended to represent, from 0° to 100° centigrade, but are found inaccurate above and below these points.

39. M. Biot, adopting still the methods and experiments of Dr Dalton, found it necessary to modify the formula in order to obtain a closer approximation to truth. Using the notation in which we have expressed Dr Dalton's method of calculation, Biot considers

$$f_n = p.\, a_n$$

as a first approximation; of which the logarithmic form is

$$\text{Log.} f_n = \text{log. } 30. + n \text{ log. } a\,;$$

which would always give the logarithm of the elastic force, provided the ratio were accurately constant; but, as it is variable in Dr Dalton's observed numbers, it would be convenient to represent the variation of the logarithm of the elastic force thus:—

$$\text{Log.} f_n = \text{log. } 30. + \alpha\, n + \beta\, n^2 + \gamma\, n^3, \text{ \&c.}$$

$\alpha$, $\beta$, $\gamma$, being constants derived from experiments thus—and setting out from 100° cent. as the zero—

If $n = 0°$ the number given by exp. is $F_0 = 30.$ in.
$n = 25$ ........................................$F_{25} = 11.250$
$n = 50$ ........................................$F_{50} = 3.500$
$n = 75$ ........................................$F_{75} = 0.910$

By substituting successively these values in the formula, we get

$$-\ 0.4259687 = 25\alpha + 625\beta + 15625.\gamma.$$
$$-\ 0.9330519 = 50\alpha + 2500\beta + 125000.\gamma.$$
$$-\ 10.5180799 = 75\alpha + .5625\beta + 4.21875.\gamma.$$

From these three equations we can readily obtain the three values wanted of $\alpha$, $\beta$, and $\gamma$, and which we find to be

$$\alpha = -\,0.01537419550$$
$$\beta = -\,0.00006742735$$
$$\gamma = +\,0.00000003381$$

and hence the whole equation

$$\text{Log. } 30.f_n = \text{log. } 30. + \alpha n + \beta n^2 + \gamma n^3$$

is now determined in English inches for the centigrade thermometer; and in order to compare it with the French observations, it is only necessary to remember that 30. in. = 0.7679 French metres, and to transform it thus:

$$\text{Log. } F_N = \text{log. } 0^{\text{m}}.76199 - 0.00112919957 - 0.01537278757 \ldots N.$$
$$- 0.00006731995N^2 + 0.00000003374N^3$$

and in the common table of logarithms

$$F_N = 0^{\text{m}}.76.10^{\,AN + BN^2 + CN^4}$$

or,

$$\text{Log. } F_N = \bar{1}.8808201 + AN + BN^2 + CN^3$$

which are almost identical with Laplace's formula (C), the degrees being reckoned positively from 100° cent. downwards, and negatively upwards.

In degrees Fahrenheit and English inches, the formula in this shape becomes—

$$\text{Log. } F_f = 1.4771213\bar{1} - 0.00854121972f$$
$$- 0.00002081091f^2 + 0.00000000580f^3 \ldots \text{D}.$$

These formulæ are far from representing the results of late experiments at high temperatures, although, within the limits of one atmosphere, they accord pretty closely with Dr Dalton's early observations.

40. In the first volume of the new series of the *Philosophical Magazine*, Mr Ivory has given a formula constructed to represent empirically the experiments of Dr Ure. It is—

$$\text{Log.}\frac{e}{30} = .0087466t - .000015178t^2 + .000000024825t^3 \text{ E.}$$

The application of this formula is laborious. It is of exactly the same nature with that of Laplace and Biot, and only represents the observations of Dr Ure within their narrow limits; extended to higher temperatures, it seems to deviate considerably from the truth, as may be seen from our table (Art. 57.)

41. Schmidt and Soldner, reviewing Dr Dalton's experiments, have each constructed a formula to represent them:

Schmidt's is—$F = t^{1.363 + .0021t}$ ..................F.

Soldner's formula is—

$$F = \text{Log. } 30.13 - \frac{(662-t)\ (212-t)}{52042} \text{ .........G.}$$

42. In the *Edinburgh Journal of Science* for 1829, Mr Tregaskis has given a theorem, which furnishes a rough approximation to experiment. It is this: that $\frac{1}{3}$ of the temperature above 32°, added to vapour, will double its elasticity.

43. M. Roche, Professor of Mathematics at Toulon, sent to the Academy of Sciences, in 1828, a memoir on this subject, in which he proposes a formula, deduced from general principles. This formula is—

$$F = 760 + 10 \frac{m\,t}{11 + 0.03\,t} \text{ .............................H}$$

This formula agrees closely with the French experiments.

44. Dr Thomas Young invented a species of formula entirely new. Abandoning altogether the formula in which one of the variables is involved as an exponent, and abandoning altogether the views from which formulæ of this kind had been derived, he assumed an expression

which is apparently perfectly arbitrary, and which has been adapted empirically to the experiments of Dr Dalton. It is this :

$$F = (1 + 0.00029) . t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad K.$$

$t$ being reckoned above 212° Fahr. and F being the force in inches of mercury. Hence we get inversely :

$$t = \frac{F^{\frac{1}{7}} - 1}{.0029}$$

For very small changes of temperature, Dr Young's formula becomes

$$t = 1.642e$$

$e$ being the corresponding slight variation of pressure from 30 inches, which corresponds, within three thousandth parts, with the mean between Deluc's correction 1.598, and Shuckburg's 1.70, or $1.645e$.

Notwithstanding the simplicity of the form of this expression, and the facilities which it presents for ready calculation, it is impossible to adopt it, as it deviates widely and rapidly from the results of observation when extended to high temperatures. Induced, however, by the simplicity of the expression, and not a little influenced, it may be, by the high authority of a name that will ever be distinguished among the most distinguished of those who have contributed immortal truths to the treasures of physical science, the example of Dr Young has drawn after it many followers. Southern, Creighton, Coriolis, Tredgold, Arago, and Dulong, have successively attempted to modify the formula of Young, so as to twist it into some measure of conformity with observed phenomena—we shall see with how little success.

45. Mr Creighton adopted a similar formula to repre-

sent Ure's experiments, only changing the constant exponent from 7 to 6; so that, making F the force of steam in inches of mercury — 0.09, and the temperature of Fahrenheit + 85° = $t$, we have

$$F = \left(\frac{t}{168.878}\right)^6 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{L.}$$

$$\text{Log. } F = (\text{Log. } t - 2.22679)^6$$

46. Mr Southern represented his experiments by the formula

$$F = \frac{(t+51.3)^{5.13}}{87344.000000.} + 0.1 \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{M.}$$

Or,

$$\text{Log. } (1.1F) = 5.13 \text{ Log. } (t+51.3) - 10.94123$$

And,

$$\text{Log. } (t+51.3) = \frac{\text{Log. } (F + 0.1) + 10.94123}{5.13}$$

47. Mr Tredgold simply reinstated Creighton's exponent, altering the co-efficient to bring it nearer to those experiments with which he was acquainted when his work was written; but it is inaccurate at high temperatures, and like that of Creighton.

$$F = \left(\frac{t+100}{177}\right)^6 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{N.}$$

48. To adapt the formula to more recent experiments, M. Coriolis (in his work *Du Calcul de l'Effet des Machines*, 4to, 1829) changed the exponent to 5.355, making it in French measures—

$$F = \left(\frac{1+0.01878\,t}{2.878}\right)^{5.355} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{O.}$$

reckoning from 0° cent. in atmospheres of 0.76 metres of mercury.

49. The French Academy of Sciences have finally reduced the index to 5.; finding that number represent their experiments at high temperatures, they adopted the following expression:

$$F = (1 + 0.7153t)^5 \text{ .............................. O.}$$

to give the elasticity in atmospheres of 0.76 metres, the temperature being in centesimal degrees, of course

$$t = \frac{F^{\frac{1}{5}} - 1}{0.7153}$$

50. In conclusion, the committee of the Franklin Institute have found it necessary to reinstate the index, 6, of Creighton, only modifying Dr Young's constant multiplier, so as to obtain

$$F = (0.00333t + 1)^6 \text{ .............................. P.}$$

51. It may be useful to collate these formulæ, and for this purpose they are assimilated in notation as follows—F being the elastic force due to a certain temperature $t$.

### Robison's Formula.

$$\text{Log. } F_t = m\ t \text{ .............................. A.}$$

### Prony's Formula.

$$F_t = \mu_{\prime} \rho_{\prime}^{t} + \mu_{\prime\prime} \rho_{\prime\prime}^{t} + \mu_{\prime\prime\prime} \rho_{\prime\prime\prime}^{t} + \text{\&c.......... B.}$$

### Laplace's Formula.

$$F_t = 0.^{m}76.\,(10)^{t.0,0154547 - t^2.0,0000625826} \text{... C.}$$

### Biot's Formula.

$$F_t = 0^{m}.76.\ (10)^{At + Bt^2 + Ct^3} \text{ ............ D.}$$

### Ivory's Formula.

$$F_t = 30.\,(0.0087466t - 0.000015178t^2 + 0.0000002483t^3) \text{ ............ E.}$$

### Schmidt's Formula.

$$F_t = t^{11\ 63 + 0021t} \text{ .............................. F.}$$

Soldner's Formula.

$$F_t = \log.\ 30.13 - \frac{(662-t)\ (212-t)}{52042.} \ldots G.$$

Roche's Formula.

$$F_t = 760.\ 10\ \frac{m\ t}{11+0.03t} \ldots\ldots\ldots\ldots\ldots H.$$

Dr Thomas Young's Formula.

$$F_t = (0.0029t + 1)^7 \ldots\ldots\ldots\ldots\ldots K.$$

Creighton's Formula.

$$F_t = \left(\frac{t}{16.57}\right)^6 \ldots\ldots\ldots\ldots\ldots L.$$

Southern's Formula.

$$F_t = \frac{(t+51.3)^{5.13}}{87344,000,000} + 0.1 \ldots\ldots\ldots\ldots\ldots M.$$

Tredgold's Formula.

$$F_t = \left(\frac{t+100}{177}\right)^6 \ldots\ldots\ldots\ldots\ldots N.$$

Coriolis' Formula.

$$F_t = \left(\frac{0.01878t+1}{2.878}\right)^{5.355} \ldots\ldots\ldots\ldots\ldots O.$$

Commission of the French Academy.

$$F_t = (0.7153t+1)^5 \ldots\ldots\ldots\ldots\ldots P.$$

Committee of the Franklin Institute.

$$F_t = (0.00333t+1)^6 \ldots\ldots\ldots\ldots\ldots Q.$$

52. From his earlier experiments Dr Dalton constructed a scale of true temperature, in which the point of freezing mercury is placed at 175°, and in the method he there adopts, the increments of the scale of true temperature are as the square roots of the corresponding expansions of the mercury from its point of maximum density. This scale was soon made the subject of a close experimental scru-

tiny by Messrs Dulong and Petit, and afterwards of less accurate, though more acrimonious, strictures by Dr Ure.

This scale was, in fact, slightly inaccurate, because it was founded on the comparatively incorrect data of the experimental physics of that date. It is, however, scarcely fair to institute a comparison between the results of a theory based on certain phenomena and the results of experiments which the improvement of our knowledge has entirely altered. It were less unjust to the theory, and more wise as regards the interests of philosophy, first to examine how far it would have been modified by recent discoveries and then to compare its results with the legitimate consequences of the data on which it rests. It ought also to be recorded, that Dr Dalton published, in the third part of his *Chemical Philosophy* in 1827, the corrected experimental results to which he had been conducted by the improved methods of observation, and the increased experience of thirty years which had elapsed from his first experiments, while modern writer's continue to use the old numbers which should have been altogether discarded.

Adopting, then, Dr Dalton's recent experiments below the point of ebullition of water, and the experiments of the French and American Institutes above that point to 24 atmospheres, let us see what theory the views of Dr Dalton would conduct us to, setting out from these improved data.

Now, Dr Dalton found that, in his experiments, a certain progression of temperatures was accompanied by a certain progression of elastic force; but his range of experiment being too small, he adopted an erroneous progression, by which, reckoning this progression as rising from the freezing point of mercury, and proceeding as the square roots of the equal expansions of mercury above that point, gave 175° as the point corresponding to the zero of the scale and the origin of his progression.

53. In examining this subject again, I have found that this gradation of temperatures, though not exact in truth, is analogous to one which may be deduced from the best experiments—and equally from Dr Dalton's and those of the French Academy. The law at which I have arrived is this—that if we reckon the temperatures from the point of congelation of mercury in a logarithmic series, the elastic force of steam forms a similar geometric series to these intervals of temperature. This would indicate that equal intervals of temperature are those which expand the substance of the thermometer through equal fractional parts of its bulk, instead of equi-differential parts as at present, so that, instead of the common arithmetical series as at present, viz.,

$$C+d+2\,d+3\,d+4\,d+\ldots\ldots\ldots\ldots n\,d\ldots\ldots\ldots\ldots\alpha$$

we should have the temperatures represented by the geometrical series

$$(C+d)\,.\,(1+d^2+d^3+d^4+\ldots\ldots d^n)\ldots\ldots\ldots\ldots\beta$$

and then the corresponding elasticities would be the geometrical series

$$(F+h)\,.\,(1+h^2+h^3+h^4+\ldots\ldots h^n)\ldots\ldots\ldots\ldots\gamma$$

54. Let us therefore endeavour to obtain the values of two such series, so as to coincide with the best experiments. For this purpose we put the series $\gamma$ into the form

$$a\,m^n=f\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\delta$$

and the series representing the progression of temperatures into the form

$$\frac{t}{r} = p^{q} \ldots\ldots\ldots\ldots\ldots\ldots \varepsilon$$

then since ($\delta$)

$$\text{Log. } a + \text{log. } m.n = \text{log.} f$$

or making *a* the unit of pressure, for simplicity, we get

$$n = \frac{\text{log.} f}{\text{log. } m}$$

whence by substitution in $\varepsilon$ when $q = n$, that is, when the elastic force is that which corresponds to the temperature *q*, we get

therefore

$$\frac{t}{r} = p \, \frac{\text{log.} f}{\text{log. } m} \ldots\ldots\ldots\ldots\ldots\ldots \zeta$$

and

$$\text{Log. } t = \frac{\text{log. } p}{\text{log. } m} \cdot \text{log.} f + \text{log. } v \ldots\ldots\ldots\ldots\ldots \eta$$

$$\text{Log.} f = (\text{log. } t - \text{log. } v) \frac{\text{log. } m}{\text{log.} p} \ldots\ldots\ldots\ldots \theta$$

When, therefore, *p* and *r* are determined for a given value of *m*, the relative is obtained. If we take the value $m = 2$, and if we take from the experiments of the French Academy and Franklin Institute, values of *t* and *f* above and below 30 inches, or unity, which is the value of *m*, and let these values be $t'$, $t''$, $f'$, $f''$; then from ($\zeta$) we have

$$\left(\frac{t'}{r}\right)^{\frac{1}{\text{log.} f'}} - \left(\frac{t''}{r}\right)^{\frac{1}{\text{log.} f''}} = 0$$

and

$$\text{log. } \left(\frac{t'}{r}\right) \text{log.} f' - \text{log. } \left(\frac{t''}{r}\right) \text{log.} f'' = 0 \ldots\ldots \iota$$

We have only, therefore, to assume $r$ so as to satisfy these conditions. Now,

$$\frac{t}{r}=\frac{t^{\text{Fahr.}}+c}{212+c}$$

that is to say, if we reckon temperature from some given point $c$ above or below the usual zero, viz. at the freezing point of mercury, like Dr Dalton's scale of temperature, and use the elastic force at 212° as our unit of pressure, we have then only to take $f'$ and $f''$ from the tables of experiment, and give such a value to $c$ as will satisfy the conditions. But as Dr Dalton places that zero at 175° we get

$$\frac{t}{r}=\frac{t^{\text{Fahr.}}+175^\circ}{387}$$

We have still to find $p$ the index of progression, corresponding to the values of $f'$ and $f''$ in the experiments.

If we take the value of $m = 2$, then since by $\zeta$

$$\left(\frac{t}{r}\right)^{\frac{\log. m}{\log. f}}=p$$

From the French experiments we get $p=1.103$, whence by substitution, $r$ being$=387^\circ$, $p=1.102$, $m=2$, we have

$$\frac{t+175^\circ}{387^\circ}=(1.103)^{\frac{\log F.}{\log 2.}}\text{......................R.}$$

From Dr Dalton's experiments we get

$$r=387^\circ,\qquad p\quad 1.1320,\qquad m=2.602,$$

whence

$$\frac{t+175^\circ}{387^\circ}=(1.1320)^{\frac{\log. F.}{\log. 2.602}}\text{.......................S.}$$

From the combination of Dr Dalton's experiments below 30 inches, with the mean between those of the

French Academy and the Franklin Institute, we get

$$r = 330^\circ, \qquad p = 1.11401, \qquad m = 2.0,$$

whence

$$\frac{t+121^\circ}{333^\circ} = (1.11401)^{\frac{\log F.}{\log. 2}} \ldots\ldots\ldots\ldots\ldots\ldots \text{T.}$$

It is from equation S and equation T that we have constructed the large table (Art. 56) in which the results of these formulæ are compared with experiment; the formulæ for high-pressure steam being compared with the mean of the French and American experiments; but, as they do not extend below 212°, that part is compared with Dr Dalton's table. The coincidence of these formulæ with experiment turns out to be much closer than could possibly have been expected where the discrepancies of experiments from each other are so great. The experiments of Dr Ure deviate from those of Dr Dalton, below the pressure of the atmosphere, as much as .33, and the greatest deviation of the formulæ is .08. At pressures above the atmosphere the maximum deviation in the first ten atmospheres between the French and American experiments amounts to 6.4°, while the maximum deviation of the formulæ is only 1.1°.—

It is, however, remarkable, that in all the experiments hitherto made, the law of elasticity below the atmospheric pressure appears to deviate considerably from that above the atmosphere—perhaps it may arise from the circumstance that the experiments below atmospheric pressure have been made with different apparatus, having errors of a different kind from those made at high pressures above the atmosphere.

From these equations we easily deduce the following formulæ in a shape convenient for calculation.

Below 212° or one atmosphere.

$$\left\{\begin{array}{l} \text{Log. } F = 7.71307\ (\text{log.} - 2.587711) \\ \text{Log. } t = 0.12965.\text{log. } F + 2.587711 \\ \text{when } t = t^{\text{Fahr.}} + 175.^{\circ} \end{array}\right\} S^{2}$$

Finally

Above 212° or one atmosphere.

$$\left\{\begin{array}{l} \text{Log. } F = 6.42\ (\text{log. } t - 2.5224442) \\ \text{Log. } t = 0.1557634.\ \text{log. } F + 52244422. \\ \text{when } t = t^{\text{Fahr.}} + 121.^{\circ} \end{array}\right\} T^{2}$$

These formulæ converted into rules are as follows :—

To find the pressure corresponding to any given temperature of steam above 212°—

*Rule.* To the temperature add 121°, find the logarithm of that sum, subtract from this logarithm the number 2.5224442, and multiply the remaining number by 6.42: the product is the logarithm of the pressure in atmospheres of 30 inches of mercury.

To find the temperature of steam, having any given pressure greater than that of the atmosphere—

*Rule.* Find the logarithm of the pressure in atmospheres, multiply it by 0.1557634, add to the product 2.5224442; the sum is the logarithm of the temperature, from which, if 121° be subtracted, the remainder will be the temperature on the common scale.

*Example.* To find the temperature at which high pressure steam will exert a force greater than the atmosphere by 195 lbs. on the inch—

195. lbs. = 390. inches of mercury,
390. inches of mercury = 13. atmospheres,
∴ 14 atmospheres = total elastic force of the steam.

Logarithm of 14 .....1.1461280
.1557634
11461280
5730640
573064
80227
6876
342
44
.17852473
Add 2.5224442

502.306 is the number of which 2.7009689 is the log.
121. being subtracted

381.306° is the temperature on Fahrenheit's scale at which the elastic force of steam has a pressure of 14 atmospheres; an elastic force of 13. × 15. lb. excess of pressure above the atmosphere on each square inch, = 195. lbs.

To find the pressure corresponding to any given temperature of steam below 212°—

*Rule.* To the temperature add 175°, find the logarithm of that sum, subtract from this logarithm the number 2.587711, and multiply the remainder by 7.71307; the product is the logarithm of the pressure in decimal parts of an atmosphere; which, if multiplied by 15, will give pounds on the square inch, and by 30, inches of mercury.

To find the temperature at which steam will have a given elastic force less than that of the atmosphere—

*Rule.* Find the logarithm of the pressure in decimal parts of an atmosphere, multiply it by 0.12965, add to the product 2.5877110; the sum is the logarithm of the temperature which will be expressed in degrees of Fahrenheit's scale, if 175 be subtracted from it.

*Example.* To find the pressure of steam at 175°.

To 170°
Add 175°

The sum is 345°, of which the log. 2.5378191
subtract 2.5877110

the remainder 1.9501081
multiplied by 7.71307

6.6507567
6650756
95010
28503
6650
—(7.71307)

The next No. is 0.412837, its log. 1.6157786
30

12.384 inches of mercury is the pressure;
being 17.616 inches of mer. below the atmos.

30.000

**By these rules the following table is calculated.**

*Table of the Elastic Force of Vapour in inches of Mercury, at different temperatures, according to our Formulæ* S$^2$ *below* 212° *and* T$^2$ *above it.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0° | 0.07 | 62° | 0.68 | 96° | 1.89 | 130° | 4.78 |
| 10 | 0.10 | 63 | 0.70 | 97 | 1.96 | 131 | 4.91 |
| 20 | 0.15 | 64 | 0.72 | 98 | 2.01 | 132 | 5.03 |
| 30 | 0.22 | 65 | 0.74 | 99 | 2.08 | 133 | 5.15 |
| *32 | 0.24 | 66 | 0.77 | 100 | 2.15 | 134 | 5.28 |
| 33 | 0.25 | 67 | 0.80 | 101 | 2.21 | 135 | 5.41 |
| 34 | 0.26 | 68 | 0.82 | 102 | 2.28 | 136 | 5.55 |
| 35 | 0.27 | 69 | 0.85 | 103 | 2.34 | 137 | 5.70 |
| 36 | 0.28 | 70 | 0.88 | 104 | 2.41 | 138 | 5.84 |
| 37 | 0.29 | 71 | 0.91 | 105 | 2.48 | 139 | 5.98 |
| 38 | 0.30 | 72 | 0.94 | 106 | 2.55 | 140 | 6.13 |
| 39 | 0.31 | 73 | 0.97 | 107 | 2.62 | 141 | 6.29 |
| 40 | 0.32 | 74 | 1.00 | 108 | 2.69 | 142 | 6.45 |
| 41 | 0.33 | 75 | 1.03 | 109 | 2.76 | 143 | 6.61 |
| 42 | 0.34 | 76 | 1.06 | 110 | 2.83 | 144 | 6.76 |
| 43 | 0.35 | 77 | 1.09 | 111 | 2.91 | 145 | 6.92 |
| 44 | 0.37 | 78 | 1.12 | 112 | 2.98 | 146 | 7.08 |
| 45 | 0.38 | 79 | 1.16 | 113 | 3.08 | 147 | 7.25 |
| 46 | 0.39 | 80 | 1.20 | 114 | 3.16 | 148 | 7.41 |
| 47 | 0.40 | 81 | 1.24 | 115 | 3.25 | 149 | 7.61 |
| 48 | 0.42 | 82 | 1.28 | 116 | 3.33 | 150 | 7.80 |
| 49 | 0.43 | 83 | 1.31 | 117 | 3.42 | 151 | 8.00 |
| 50 | 0.45 | 84 | 1.36 | 118 | 3.51 | 152 | 8.20 |
| 51 | 0.47 | 85 | 1.39 | 119 | 3.60 | 153 | 8.40 |
| 52 | 0.49 | 86 | 1.44 | 120 | 3.69 | 154 | 8.59 |
| 53 | 0.51 | 87 | 1.47 | 121 | 3.79 | 155 | 8.79 |
| 54 | 0.53 | 88 | 1.51 | 122 | 3.88 | 156 | 8.99 |
| 55 | 0.55 | 89 | 1.56 | 123 | 3.98 | 157 | 9.20 |
| 56 | 0.57 | 90 | 1.61 | 124 | 4.08 | 158 | 9.41 |
| 57 | 0.59 | 91 | 1.65 | 125 | 4.19 | 159 | 9.62 |
| 58 | 0.61 | 92 | 1.69 | 126 | 4.30 | 160 | 9.84 |
| 59 | 0.62 | 93 | 1.74 | 127 | 4.42 | 161 | 10.06 |
| 60 | 0.64 | 94 | 1.79 | 128 | 4.53 | 162 | 10.28 |
| 61 | 0.66 | 95 | 1.84 | 129 | 4.66 | 163 | 10.51 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 164° | 10.75 | 192° | 19.86 | 220° | 35.35 | 248° | 58.48 |
| 165 | 11.01 | 193 | 20.30 | 221 | 36.08 | 249 | 59.37 |
| 166 | 11.28 | 194 | 20.74 | 222 | 36.80 | 249.7 | 60.00 |
| 167 | 11.56 | 195 | 21.19 | 223 | 37.54 | 250. | 60.27 |
| 168 | 11.85 | 196 | 21.64 | 224 | 38.31 | 274.1 | 90.00 |
| 169 | 12.05 | 197 | 22.11 | 225 | 39.11 | 291.9 | 120.00 |
| 170 | 12.36 | 198 | 22.57 | 226 | 39.94 | 306.8 | 150.00 |
| 171 | 12.66 | 199 | 23.04 | 227 | 40.70 | 319.2 | 180.00 |
| 172 | 12.96 | 200 | 23.52 | 228 | 41.66 | 329.9 | 210.00 |
| 173 | 13.26 | 201 | 24.00 | 229 | 42.55 | 339.3 | 240.00 |
| 174 | 13.56 | 202 | 24.50 | 230 | 43.46 | 348.8 | 270.00 |
| 175 | 13.86 | 203 | 25.00 | 231 | 44.29 | 355.6 | 300.00 |
| 176 | 14.16 | 204 | 25.52 | 232 | 45.14 | 363.0 | 330.00 |
| 177 | 14.47 | 205 | 26.05 | 233 | 45.95 | 369.4 | 360.00 |
| 178 | 14.78 | 206 | 26.59 | 234 | 46.78 | 375.5 | 390.00 |
| 179 | 15.09 | 207 | 27.14 | 235 | 47.58 | 381.3 | 420.00 |
| 180 | 15.41 | 208 | 27.69 | 236 | 48.39 | 387.0 | 450.00 |
| 181 | 15.73 | 209 | 28.25 | 337 | 49.21 | 391.9 | 480.00 |
| 182 | 16.06 | 210 | 28.83 | 238 | 50.04 | 396.7 | 510.00 |
| 183 | 16.40 | 211 | 29.40 | 239 | 50.86 | 401.3 | 540.00 |
| 184 | 16.75 | *212 | 30.00 | 240 | 51.70 | 405.8 | 570.00 |
| 185 | 17.10 | 213 | 30.61 | 241 | 52.53 | 410.0 | 600.00 |
| 186 | 17.46 | 214 | 31.24 | 242 | 53.37 | 444.6 | 900.00 |
| 187 | 17.83 | 215 | 31.89 | 243 | 54.22 | 470.5 | 1200.00 |
| 188 | 18.21 | 216 | 32.56 | 244 | 55.07 | 491.4 | 1500.00 |
| 189 | 18.60 | 217 | 33.24 | 245 | 55.93 | | |
| 190 | 19.00 | 218 | 33.93 | 246 | 56.73 | | |
| 191 | 19.42 | 219 | 34.63 | 247 | 57.60 | | |

55. The formulæ thus given are in such perfect accordance with our best experimental knowledge, that we cannot withhold our assent from the correctness of the principles from which they have been deduced. At the same time we desiderate very much a better series of experiments than we yet possess, as the range of doubtful temperature above 212° is far wider than the present perfect state of experimental science, and our improved means of observing, can at all warrant. The discrepancies between the

experiments above and below 212° show, that the two series should if possible be performed with identical apparatus.

The formulæ we have obtained have been founded on the *hypothesis, that bodies expand nearly equal proportions of bulk in equal intervals of true temperature ; and we have found that the elastic force of steam increases in equal proportions, from equal increments of temperature, reckoned in true intervals from the bottom of the scale.*

Our formula should, however, be capable of being reduced into a form closely resembling those which have preceded it, in so far as these have represented approximately the experiments they were made to represent; thus the formula of Laplace and his followers is of the form

$$F = C^{m t + m t^2 + m t^3 + \&c. \textit{ ad infinitum.}}$$

So, in like manner, we should obtain from Equation T the following :

$$\text{Log. } 2 \times \left\{ 2 \log . c - \log .(c - t^\circ) - k\left(\frac{t^2}{c^2} + \frac{c^4}{2c^4} + \frac{t^6}{3c^6} + \&c.\right.\right\}$$

$$-\log . C - \log .(1.11401) \log . F = 0$$

which is easily presented in a form absolutely the same.

In like manner, it may be presented at once in the form adopted by Dr Thomas Young and all his followers, viz.

$$\left(\frac{m t + c}{c}\right) = F_t$$

for, if we take our formula $S_2$

$$\text{Log. } F = 7.71307 (\log . t - 2.587711)$$

we get, resuming the natural number,

$$F = \left(\frac{t + 175}{387}\right)^{7.713} \quad \ldots\ldots\ldots\ldots\ldots\ldots S_3.$$

Or, if we take formula $T_2$, we get

$$F = \left(\frac{t + 121}{333}\right)^{6.42} \quad \ldots\ldots\ldots\ldots\ldots\ldots T_3.$$

We thus find, that the old formulæ have all approximated in a greater or less degree to the representation of the very hypothesis on which ours has now been formed. They thus add greatly to the probability of its truth.

We do not, however, mean to assert, that the zero of the mercurial thermometer is absolutely at 175° or 121° below the present 0, or that the progression of the temperatures has been fixed accurately for mercury or for vapour. On the contrary, we have seen that the discrepancies of the results obtained by different physical experimenters are great, and do not admit of obtaining unchangeable numerical indices of progression, either of the temperatures or the corresponding elastic force. The existence of these two progressions, and their character has, we think, been established, and our research has the effect of confirming the profound views of Dr Dalton, which have, we think, been ill understood and insufficiently appreciated.

56. The following table exhibits some formulæ and experiments collated:

*Table of the force of Steam at different temperatures from 0° to 500°.*

| I. Temperature. Fahrenheit. | II. Dalton. | III. Ure. | IV. Young. | V. Ivory. | VI. Tredgold. | VII. Southern. | VIII. Robison. | IX. Watt. | X. Frank. Inst | XI. New Formula. | XII. Diff. Dalt. & Ure's Expts. | XIII. Diff. Acad. Inst. | XIV. Diff. Tred. & Dalton. | XV. Diff. New Formula & Dalton. | XVI. Temperature. Fahrenheit. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0° | 0.08 | ... | ... | ... | ... | ... | ... | ... | ... | 0.07 | ... | ... | ... | —.01 | 0° |
| 10 | 0.12 | ... | ... | ... | ... | ... | ... | ... | ... | 0.10 | ... | ... | ... | —.02 | 10 |
| 20 | 0.17 | ... | 0.11 | ... | ... | ... | ... | ... | ... | 0.15 | ... | ... | —.09 | —.02 | 20 |
| 32 | 0.26 | 0.20 | 0.18 | ... | 0.17 | 0.16 | 0.00 | ... | ... | 0.24 | —.06 | ... | —.10 | —.02 | 32 |
| 40 | 0.34 | 0.25 | 0.20 | ... | 0.24 | 0.22 | 0.10 | ... | ... | 0.32 | —.09 | ... | —.11 | —.02 | 40 |
| 50 | 0.49 | 0.36 | 0.36 | 0.36 | 0.37 | 0.33 | 0.20 | ... | ... | 0.45 | —.13 | ... | —.10 | —.04 | 50 |
| 60 | 0.65 | 0.52 | 0.53 | ... | 0.55 | 0.48 | 0.35 | ... | ... | 0.64 | —.13 | ... | —.09 | —.01 | 60 |
| 70 | 0.87 | 0.73 | 0.75 | 0.73 | 0.78 | 0.68 | 0.55 | 0.77 | ... | 0.88 | —.14 | ... | —.05 | +.01 | 70 |
| 80 | 1.16 | 1.01 | 1.05 | ... | 1.11 | 0.95 | 0.82 | ... | ... | 1.20 | —.16 | ... | —.06 | +.04 | 80 |
| 90 | 1.59 | 1.36 | 1.44 | 1.36 | 1.53 | 1.34 | 1.18 | ... | ... | 1.61 | —.23 | ... | —.04 | +.02 | 90 |
| 100 | 2.12 | 1.86 | 1.95 | ... | 2.08 | 1.84 | 1.60 | 1.55 | ... | 2.15 | —.24 | ... | —.00 | +.03 | 100 |
| 110 | 2.79 | 2.45 | 2.62 | 2.46 | 2.79 | 2.56 | 2.25 | ... | ... | 2.83 | —.34 | ... | +.05 | +.04 | 110 |
| 120 | 3.63 | 3.30 | 3.46 | ... | 3.68 | 3.46 | 3.00 | ... | ... | 3.69 | —.33 | ... | +.10 | +.06 | 120 |
| 130 | 4.71 | 4.37 | 4.54 | 4.41 | 4.81 | 4.43 | 3.95 | ... | ... | 4.78 | —.34 | ... | +.16 | +.07 | 130 |
| 140 | 6.05 | 5.78 | 5.88 | ... | 6.21 | 5.75 | 5.15 | 5.14 | ... | 6.15 | —.27 | ... | ... | +.08 | 140 |
| 150 | 7.73 | 7.53 | 7.55 | 7.42 | 7.94 | 7.46 | 6.72 | ... | ... | 7.80 | —.20 | ... | +.21 | +.07 | 150 |
| 160 | 9.79 | 9.60 | 9.62 | ... | 10.05 | 9.52 | 8.65 | 8.92 | ... | 9.85 | —.19 | ... | +.26 | +.06 | 160 |
| 170 | 12.31 | 12.05 | 12.14 | 12.05 | 12.60 | 12.14 | 11.05 | 11.37 | ... | 12.38 | —.26 | ... | +.29 | +.07 | 170 |
| 180 | 15.38 | 15.16 | 15.23 | ... | 15.67 | 15.20 | 14.05 | 14.73 | ... | 15.41 | —.28 | ... | +.29 | +.03 | 180 |
| 190 | 18.98 | 19.00 | 18.96 | 18.93 | 19.00 | ... | 17.85 | 19.00 | ... | 18.90 | +.12 | ... | +.02 | +.02 | 190 |
| 200 | 23.51 | 23.60 | 23.44 | ... | 23.71 | ... | 22.62 | ... | ... | 23.52 | +.09 | ... | +.20 | +.01 | 200 |
| 210 | 28.82 | 28.88 | 28.81 | 28.81 | 28.86 | ... | 28.65 | ... | ... | 28.82 | +.07 | ... | +.04 | +.00 | 210 |
| 212 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 29.40 | ... | 30.00 | 0.00 | ... | +.00 | 0.00 | 212 |
| 220 | 35.18 | 35.54 | 35.19 | ... | 34.92 | ... | 35.8 | 33.65 | ... | 35.10 | —0.36 | ... | —.26 | —.15 | 220 |
| 230 | 44.60 | 43.10 | 42.47 | 42.63 | 42.00 | ... | 44.5 | 40.+ | ... | 42.60 | —1.50 | ... | —2.13 | —2.00 | 230 |
| 240 | 53.45 | 51.70 | 51.66 | ... | 50.24 | ... | 54.9 | 49.0 | ... | 51.42 | —1.75 | ... | —3.21 | 2.03 | 240 |

## *Table of the Force of Steam at different Temperatures (continued).*

| I. Pressure in Atmospheres. | II. French Acad. | III. Dr Ure. | IV. Young. | V. Ivory. | VI. Tredg. | VII. Southern. | VIII. Robison. | IX. Watt. | X. Franklin Institute | XI. New Form. | XII. Diff. Dr Ure's Experimts. | XIII. Diff. Acad. Inst. | XIV. Diff. Tred. & Dalton. | XV. Diff. New Form & Ac. Inst | XVI. Pressure in Atmospheres. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1st At. | 212.0° | 212° | 212° | 212° | 212° | ... | 212° | 212° | 212° | 212° | 0.00 | 000.2 | 0.00° | 0.00° | 1st At. |
| 2d At. | 250.5 | 250.0 | 240.3 | 249 | 250.+ | 250.3+ | ... | 252.5 | 250.0 | 249.7 | ... | — 0.5 | 0.+ | — 0.55 | 2d At. |
| 3d At. | 275.2 | 275.0 | 271 | ... | 274.+ | ... | 267 | ... | 275.2 | 274.1 | ... | — 0.2 | — 1.+ | — 1.0 | 3d At. |
| 4th At. | 293.7 | 291.5 | 288 | 290 | 294.+ | 293.4+ | ... | ... | 291.5 | 291.9 | ... | — 2.2 | +1.4 | — 0.7 | 4th At. |
| 5th At. | 308.8 | 304.5 | 302 | ... | 309.+ | ... | ... | ... | 304.5 | 306.8 | ... | — 4.3 | +3.7 | — 0.1 | 5th At. |
| 6th At. | 320.4 | 315.5 | ... | ... | 322.— | ... | ... | ... | 315.5 | 319.2 | ... | — 4.9 | +4.0 | +1.2 | 6th At. |
| 7th At. | 331.7 | 325.5 | ... | ... | ... | ... | ... | ... | 326.5 | 329.9 | ... | — 5.7 | ... | +1.1 | 7th At. |
| 8th At. | 342.0 | 336.0 | ... | 337 | 342.+ | 343.6+ | ... | ... | 336.0 | 339.3 | ... | — 6.0 | +3.3 | +0.3 | 8th At. |
| 9th At. | 350.0 | 345 | ... | ... | ... | ... | ... | ... | 345.0 | 348.8 | ... | — 5.0 | ... | +0.9 | 9th At. |
| 10th At. | 358.9 | ... | ... | ... | ... | ... | ... | ... | 352.5 | 355.6 | ... | — 6.4 | ... | — 0.1 | 10th At. |
| 11th At. | 366.8 | ... | ... | ... | ... | ... | ... | ... | ... | 363.0 | ... | ... | ... | ... | 11th At. |
| 12th At. | 374.0 | ... | ... | ... | 372.— | ... | ... | ... | ... | 369.4 | ... | ... | +3.0 | ... | 12th At. |
| 13th At. | 380.6 | ... | ... | ... | ... | ... | ... | .. | ... | 375.5 | ... | ... | ... | ... | 13th At. |
| 14th At. | 386.9 | ... | ... | ... | ... | ... | ... | ... | ... | 381.3 | ... | ... | ... | ... | 14th At. |
| 15th At. | 392.8 | ... | ... | ... | ... | ... | ... | ... | 383.8 | 387.0 | ... | — 9.0 | ... | — 0.3 | 15th At. |
| 16th At. | 398.5 | ... | ... | ... | ... | ... | ... | ... | ... | 391.9 | ... | ... | ... | ... | 16th At. |
| 17th At. | 403.8 | ... | ... | ... | ... | ... | ... | ... | ... | 396.7 | ... | ... | ... | ... | 17th At. |
| 18th At. | 408.9 | ... | ... | ... | ... | ... | ... | ... | ... | 401.3 | ... | ... | ... | ... | 18th At. |
| 19th At. | 413.9 | ... | ... | ... | ... | ... | ... | ... | ... | 405.8 | ... | ... | ... | ... | 19th At. |
| 20th At. | 418.5 | ... | ... | ... | 414 | ... | ... | ... | 405 | 410. | ... | — 13.5 | +2.3 | — 1.7 | 20th At. |
| 30th At. | 457.2 | ... | ... | ... | ... | ... | ... | ... | ... | 444.6 | ... | ... | ... | ... | 30th At. |
| 40th At. | 466.6 | ... | ... | ... | ... | ... | ... | ... | ... | 470.5 | ... | ... | ... | ... | 40th At. |
| 50th At. | 510.6 | ... | ... | ... | ... | ... | ... | ... | ... | 491.4 | ... | ... | ... | ... | 50th At. |

The first and last columns contain the successive temperatures, as far as 240°, and after that the number of atmospheres of pressure; and their reference extends wholly across the table.

Col. II. contains the later experiments of Dr Dalton, interpolated, where necessary, down to 240°; the remainder of that column is from the experiments of the French Academy.

Col. III. contains the experiments of Dr Ure.

Cols. IV. V. and VI. contain the formulæ of Dr Young, Mr Ivory, and Mr Tredgold.

Cols. VII. VIII. IX. and X. contain the experiments of Southern, Robison, Watt, and the Franklin Institute.

Col. XI. contains the numbers given by our formulæ.

Col. XII. exhibits the differences between the experiments of Drs Dalton and Ure.

Col. XIII. exhibits the differences between the experiments of the French Academy and the Franklin Institute.

Col. XIV. exhibits the deviations of Tredgold's formula from Dalton's experiments, down to 240°; and below that point, from the mean of the experiments of the French Academy and the Franklin Institute, interpolated where required.

Col. XV. exhibits the difference between our formulæ and the best experiments, Dr Dalton's being taken down to 240°; and the mean between those of the French Academy and the Franklin Institute from that point to the end of the table—interpolations being used when necessary.

## SECTION IV.—ON THE CONSTITUTIONAL CALORIC OF STEAM, ITS DENSITY AND VOLUME AT DIFFERENT TEMPERATURES, AND ITS GENERATION AND CONDENSATION.

57. Having now ascertained the force that may be given to steam by heating water in a confined space, so that we can always obtain any force we desire by raising it to the proper temperature, we have next to enquire what quantity of heat is necessary to produce steam of that temperature and force. The answer to this question is, to determine the quantity of fuel necessary to generate steam of a given power, and direct the economic application of that power.

The quantity of caloric necessary to transform a given quantity of water into steam of the same temperature, is called the *caloric of elasticity* of that substance. The quantity of heat which it will contain at any given temperature is called its *capacity* for heat; and the relation which subsists between the quantity of heat which some well known body, such as water or air, gives out or acquires, in a given change of temperature, and that which any other substance will give out or acquire in the same circumstances, is called the *specific caloric* of that substance.

58. Of the quantity of the caloric of elasticity of any substance, of its capacity for containing heat, and of its specific caloric, the *thermometer* gives us no information. An instrument for doing so may be called, as a distinction, the *calorimeter*. Thus the thermometer measures the intensity of heat—the calorimeter its quantity.

If in three several vessels there be contained, at the temperature of 32°, a pound weight of three different fluids, water in one, mercury in the second, and oil in the third; and if the heat of an alcohol lamp be applied, first of all to the mercury, then to the water, and next to the oil, a thermometer being inserted in each, it will require much longer time to heat the water to 212° of the thermometer than the mercury, twenty-five times as much alcohol being burned in the process; whereas the oil will be warmed to the same temperature on the thermometer, by half the quantity of caloric which is necessary to heat the water to 212°. Therefore, the capacity of water for heat is said to be twenty-five times as great as that of mercury, and twice as great as the capacity of oil; and the specific heats of these substances, in relation to water, are thus represented:

Water, 1.000; oil, 0.520; mercury, 0.040 nearly.

If, instead of taking equal weights of these substances, we had filled equal vessels with them, and then applied the quantity of water necessary to heat them to equal temperatures, we should have had the capacities and specific heat of equal volumes, instead of equal masses as formerly; and it would have been found, that the quantity of alcohol required to heat them to the same temperature was only half as much for the mercury as the water, and greater for the water than the oil, in the proportion of 20 to 9; showing that the capacity of water was still the greatest, and that the specific caloric, in equal volumes of these substances, are nearly

Water, 1.000; oil, 0.450; mercury, 0.550.

The capacities for heat, and the specific caloric of different substances, may be determined by cooling as well as heating them. An ounce of ice thrown upon a pound of mercury will cool it or an equal weight of oil much more than water; and, in general, the quantity of ice, or of cold water, or of cold air, or any other fluid required to cool a body, will exactly correspond to the quantity of caloric required to heat it to the same degree of temperature. A calorimeter measures the quantity of ice which must be melted in cooling different substances, and is described in our article "HEAT." The following are the results of such of the most valuable experiments upon this subject as are appropriate to our present enquiry:

*Table of the specific Caloric in different substances.*

| | Equal Weights. | Equal Volumes. | |
|---|---|---|---|
| Water, . . . . | 1.000 | 1.000 | |
| Mercury, . . . . | 0.033 | 0.470 | Dulong and Petit. |
| Alcohol, . . . . | 0.700 | 0.570 | Dalton. |
| Sulphuric ether, . | 0.660 | 0.500 | Dalton. |
| Spermaceti oil, . | 0.520 | 0.450 | Dalton. |
| Olive oil, . . . . | 0.309 | ....... | Lavoisier & Laplace. |
| Sulphuric acid, . | 0.350 | 0.650 | Dalton. |
| Nitric acid, . . . | 0.620 | 0.870 | Dalton. |
| Muriatic acid, . . | 0.600 | 0.700 | Dalton. |
| Sol. of salt (1.197) | 0.780 | 0.930 | Dalton. |
| Sol. of sugar (1.117) | 0.770 | 0.900 | Dalton. |
| Ice, . . . . . | 0.900 | 0.830 | Dalton. |
| Coal, . . . . . | 0.280 | 0.360 | Dalton. |
| Flint glass, . . . | 0.190 | 0.550 | Dalton. |
| Iron, . . . . . | 0.110 | 0.880 | Dulong and Petit. |
| Copper, . . . . | 0.095 | 0.850 | Dulong and Petit. |
| Lead, . . . . . | 0.040 | 0.450 | Dalton. |
| Tin, . . . . . | 0.070 | 0.510 | Dalton. |
| Zinc, . . . . . | 0.100 | 0.690 | Dalton. |

| | | | | |
|---|---|---|---|---|
| Silver, | 0.055 | | | Dulong and Petit. |
| Gold, | 0.029 | | | Dulong and Petit. |
| Platina, | 0.335 | | | Dulong and Petit. |
| Atmospheric air, | 0.267 | 1.000* | 1.000* | Delaroche and Berard. |
| Hydrogen gas, | 3.294 | 12.340 | 8.903 | |
| Oxygen gas, | 0.236 | 0.885 | 0.976 | |
| Nitrogen gas, | 0.275 | 1.032 | 1.000 | |
| Nitrous oxide gas, | 0.237 | 0.888 | 1.350 | |
| Olefiant gas, | 0.420 | 1.576 | 1.553 | |
| Carbonic oxide gas, | 0.288 | 1.080 | 1.034 | |
| Carbonic acid gas, | 0.221 | 0.828 | 1.258 | |

59. Besides the capacity of different bodies for heat, and the specific heat of each at given temperatures, there is another condition of heat still more striking, and of which the thermometer gives no indication. It is this: that the same substance, at different times, may contain different quantities of caloric, and yet the thermometer in both cases give the same indication of temperature. Ice at 32°, which is in the process of melting, and while its bulk is diminishing by one-tenth part, receives as much caloric as would raise its temperature, when melted, to 172°; and after having received it all, remains still at the same temperature as before, indicating 32° on the thermometer. In like manner, when the particles of the water have acquired so much sensible heat as to raise its temperature to 212°, it may receive as much more heat as would have raised its temperature 950° or 960°, if it had continued to be shown by the thermometer; but the water now assuming the state of steam, the thermometer indicates no ac-

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* In these two columns, air is assumed as unity, the first being the specific heat under equal weights, and the second under equal volumes.

cession, but remains in the water or in the steam still at the temperature of 212°. In these two conditions, therefore, when the particles of ice are leaving the solid and taking the liquid form, and again passing out of the liquid into the vaporous state, a large accession of caloric passes into the substance without being detected by the thermometer; this heat, *insensible* to the thermometer, and manifested only by the calorimeter, is called LATENT HEAT. The doctrine of latent heat was discovered by Dr Black.

The quantity of heat thus latent in the mass of a solid, when it assumes the liquid state, is called the *caloric of fluidity*. The latent caloric of a liquid passing into vapour is called the caloric of elasticity or vaporization.

| Caloric of Fluidity. | | Caloric of Vaporization. | |
|---|---|---|---|
| Sulphur, . . | 144° | Water, . . | 967° |
| Spermaceti, . | 145 | Alcohol, . . | 442 |
| Lead, . . | 162 | Ether, . . | 302 |
| Bees' wax, . . | 175 | Petroleum, . . | 178 |
| Zinc, . . . | 493 | Oil of turpentine, | 178 |
| Tin, . . . | 500 | Nitric acid, . | 532 |
| Bismuth, . . | 550 | Liquid ammonia, | 837 |
| Ice, . . . | 140 | Vinegar, . . | 875 |

60. The determination of the latent heat of ordinary steam is a problem of considerable practical difficulty. It may be obtained rudely by very simple contrivances. If a lamp, which burns with tolerable uniformity, be applied to a vessel containing cold water, at the temperature of 32°, so long as to heat it to 212°, the boiling point, and if the lamp be then weighed and the consumption of oil ascertained by the loss of weight; and if the lamp be still applied to the boiling water so as to keep it constantly in ebullition until the whole has been converted into steam; the steam passing off at the same temperature as the

water, it will be found, when the whole water has been boiled away, or converted into steam, that 6 times as much oil has been consumed, or that 6 times as much heat has been employed in the conversion of the water into steam as was required formerly to heat the water from 32° to 212° or to give it 180°, of temperature; so that 6 times 180° or 1080°, will appear to have been absorbed or carried off in the steam of 212°—that is, the latent heat of steam is 1080°.

Otherwise, the same determination may be obtained, if the steam, when passing off from the boiling water, be led carefully in a pipe to a vessel of cold water, so as to take from it the heat which it has thus carried off; if the water to which the heat of the steam is given out be at a temperature of 32° and of 6 times the quantity of the water from which the steam was formed, the whole of it will be heated by the caloric of the steam to 212°, showing that the quantity of caloric of the steam amounts to what gives 180° to 6 times the quantity of water; giving, as formerly, 6 times 180° or 1080° as the amount of the latent heat of the steam.

It is to Mr Watt that we owe the earliest determination of the latent heat of steam. Dr Black endeavoured to ascertain this point by the first of the methods we have pointed out, by comparing the time of raising the temperature of water a certain number of degrees, with the time of boiling it off a certain number of degrees; but his result was not correct, being only 800°. Mr Watt's result for the latent heat of steam was 1006° 79.

Mr Southern's experiments were made in 1803; and he was assisted in them by Mr William Creighton, and communicated them to Mr Watt for an appendix to this article.

He obtained the number 950°. The thermometers employed in his experiments were made and graduated with the greatest care, the tubes having been accurately measured as to the proportional capacity of their different parts.

A similar series of experiments was afterwards made by M. Schmidt, who determined the heat latent in steam to be about 5.33 times that necessary to heat water from 32° to 212° = 5.33 times 180° or 960 nearly.

Count Rumford determined the latent heat of steam by condensing it in a calorimeter formed by pushing a long spiral steam pipe through a vessel of cold water, by which he obtained 1040.8 as the latent heat of steam of water.

M. Despretz in the *Annales de Chimie et Physique,* gives 955.8° as the result of his experiments on the latent heat of steam.

Lavoisier and Laplace make the latent heat of steam 1000°.

From the experiments of Gay Lussac and of MM. Clement and Desormes, the number 990° is generally used by the French to represent the latent heat of steam. The diversity of the results obtained from experiments made by so many excellent experimenters, with so much precaution, is remarkable—to eliminate from them the precise truth with certainty is not within our present resources of analysis. There is high probability in favour of the numbers 990. or 1000., as representing nearly enough the latent heat of steam, being 5.555 times the caloric of boiling water, its whole caloric reckoned from 32° being 6.666 times that of boiling water.

61. A doctrine of great simplicity is now pretty generally held as expressing with an accuracy quite within

the limits of experimental precision, the result of our knowledge of the heat latent in steam. It is found that in steam of great elasticity and of corresponding high temperature, the heat latent is in quantity less; and that, on the contrary, when steam is of lower elastic force and of lower temperature than at 212°, its latent heat is greater than at 212°. And it appears that we are warranted in the conclusion first suggested by Mr Watt and afterwards by Dr Dalton, that the whole amount of caloric in a given quantity of elastic vapour remains the same at all temperatures and under all pressures. When the volume of the vapour is great, the greater is its capacity and the less its temperature; while, by compressing it into smaller space, its elasticity is encreased and its temperature raised. The doctrine is thus expressed, *that the sum of the sensible and latent heat of vapour is a constant quantity.* M. Despretz has extended this to the vapours of several other fluids.

There is another expression for the law of the constitutional heat of the vapour, which is, in the language of the Atomic Theory, *that every atom of a fluid in the state of vapour possesses, under every degree of elasticity and pressure, the same quantity of caloric.* This doctrine leads to very important consequences both of a theoretical and practical nature.

It follows immediately from this doctrine, that if a quantity of vapour have once been formed by adding to the liquid the quantity of caloric necessary to the constitution of the vapour, the same particles of matter surrounded by the same spheres of caloric may pass through all gradations of density, and through all gradations of temperature, without either parting with caloric or obtaining fresh supplies. Vapour of the temperature of 212°, as it rises from water boiling in the open air, may be collected in a vessel and compressed by the force of 30 inches of mercury into half its bulk, it will become steam of a higher temperature viz. 250°, from the increased quantity of caloric in the diminished volume, and in this case the latent heat will only be 970° instead of 1000°. If compressed still further again into one half of that bulk, the temperature will rise to 292°, and leave only 920° latent. Compressed still further into half of the last-mentioned space, that is into ⅛ of its original bulk, the temperature is raised to 339°, leaving only 873° latent; and another step would raise the temperature to 392°, leaving only 820° latent; less than seven steps more would bring the steam into less than its original bulk of water, with a temperature of between 900° and 1000° of sensible heat, and an amount of latent heat not much greater than its original proportion of sensible heat, or 212°. In this case, we should have steam as heavy as water and as hot as flame.

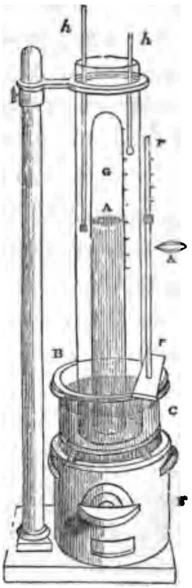
If, on the contrary, this process were reversed, and the steam produced at 212° under the pressure of an atmosphere permitted to expand in vacuo to double its bulk, a portion of the sensible heat would become absorbed into the spheres of caloric around the atoms of water, increasing the latent heat by 32°, and diminishing the sensible heat to 180°. The bulk being again doubled, and the steam expanded to four times its original bulk, the temperature would sink to 150°, and three more repetitions of the expansion would give a vapour of 71° temperature, and 1141° of latent heat.

This expansion and contraction of the steam, accompanied by diminished temperature, is exactly what would exist if our atmosphere, instead of oxygen and nitrogen, were wholly composed of vapour of water. Suppose the temperature of the ocean to be 1000°, an atmosphere of vapour would be raised of 2000 times the weight of the present atmosphere: the under-part of this atmosphere, compressed by the superincumbent weight, would be of great density; but in ascending, the diminished pressure would be attended with diminished temperature, until at last a cloud of white ice would be seen floating on the surface. Must not the sun, from his intense heat, be a body of this nature, having an atmosphere of enormous depth, on the summit of which the beautifully crystalline and sparkling crust is continually preserved by its diminished temperature in a state of renewed whiteness?

62. The specific gravity, density, and volume occupied by steam at different temperatures, have been correctly determined by experiment; and it has been ascertained that the expansion of vapour follows the law of the expansion of other gases by heat; viz. the law of Dalton and Gay Lussac, that all gases expand from 1. to 1.375 in bulk, by 180° of temperature, or $\frac{1}{480}$ for each degree of Fahrenheit; and, secondly, that steam obeys the law of Boyle and Mariotte, contracting in volume proportionally to pressure. It is first of all necessary to know what bulk a given quantity of water converted into steam will occupy at a given pressure, and the application of these laws will determine the specific gravity, density, and volume at all other pressures and temperatures.

63. The experiments of Gay Lussac upon this subject are simple, elegant, and satisfactory. His apparatus is as follows:—A chauffer, F, contains burning fuel, by which heat is communicated to B C, a bath of mercury. A

Fig. 23.



spherule A, of thin glass, hermetically closed, contains a given weight of water. G is a glass tube of considerable diameter, filled with pure dry mercury, and inserted in the bath, after which the spherule A, containing the water, is allowed to ascend to the top of the mercury, and is then broken by concussion, so that a given quantity of water is thus placed in the Torricellian vacuum at the top of the mercury. By the fuel in F heat is then communicated upwards, by the fluids, to the whole apparatus, and to the water in the summit of the tube G; and the mercury descends until the whole of the water is converted into steam, after which it ceases to descend in the same rapid proportion to the increase of temperature. This change shows that the whole of the water is evaporated, and the heat must again be allowed gradually to diminish, until the depression of the mercury corresponds to the temperature indicated in our table of Elastic Force. The capacity of the tube G is shown by divisions on its surface previously fixed, and the height of the mercurial column by a graduated rule and vernier *r r*, supported on the edge of the bath. The thermometers *h h* indicate the temperature of the fluids.

By means of this apparatus, Gay Lussac has determined the specific gravity of steam to be .625, air being 1000.; that is to say, steam from boiling water is lighter than common air in the proportion of 5. to 8.

64. Dr Dalton's recent experiments make the weight of a cubic foot of air at 60° = 535.68 grains; therefore a cubic foot of common steam weighs 334.8 grains at 60°, under a pressure of 30 inches of mercury; but as this pressure would convert it into water, the true weight will be found, by the law of Mariotte, thus:

$$30 \text{ in.} : .065 :: 334.8 : 7.254$$

the true weight, in grains, of a cubic foot of steam at 60°, and under the former pressure due to its own elasticity in vacuo ; but if we wish to know the weight of a cubic foot of steam at 212°, we must use the law of Gay Lussac and Dalton, thus:

$$\frac{(212^\circ - 60^\circ) \text{ or } 152^\circ}{480} + 1 : 1 :: 334.8 : 254.3$$

254.3 grains is therefore the weight of a cubic foot of steam, as it passes off from water boiling in the air at 212°.

But the weight of one cubic inch of water at 60° is 253 grains ; therefore, the weight of a cubic inch of water at 60° is almost exactly equal to one cubic foot, or 1728 cubic inches, of steam.

Hence we find, that the particles of water, when they form steam, are so much repelled by their spheres of caloric, as to be kept at twelve times their original distance from each other ; that, in this gaseous state, water is 1728 times rarer than when liquid ; and that one gallon of water, with the requisite supply of caloric, will make 1728 gallons of steam.

## *Dr Dalton's Table of the Density of Air and Steam.*

| 100 cubical inches of air under 30 in. Barom. and 60° Fahrenheit, being 31 grs. | | | |
|---|---|---|---|
| Temperature. | Vol. Air. under 30 in. | Weight of 100 cubic inches of steam. | Elasticity of steam. |
| Fahr. 32° | 480 | .178 grs. | 0.26 |
| 34 | 482 | .191 | 0.28 |
| 36 | 484 | .203 | 0.30 |
| 38 | 486 | .206 | 0.32 |
| 40 | 488 | .229 | 0.34 |
| 42 | 490 | .245 | 0.37 |
| 44 | 492 | .267 | 0.40 |
| 46 | 494 | .284 | 0.43 |
| 48 | 496 | .303 | 0.46 |
| 50 | 498 | .323 | 0.49 |
| 52 | 500 | .341 | 0.52 |
| 54 | 502 | .366 | 0.56 |
| 56 | 504 | .384 | 0.59 |
| 58 | 506 | .402 | 0.62 |
| 60 | 508 | .420 | 0.65 |
| 62 | 510 | .444 | 0.69 |
| 64 | 512 | .468 | 0.73 |
| 66 | 514 | .492 | 0.77 |
| 68 | 516 | .521 | 0.82 |
| 70 | 518 | .551 | 0.87 |
| 72 | 520 | .580 | 0.92 |
| 74 | 522 | .610 | 0.97 |
| 76 | 524 | .645 | 1.03 |
| 78 | 526 | .680 | 1.09 |
| 80 | 528 | .721 | 1.16 |

65. The source from which caloric is obtained for the conversion of water into steam, is either the heat of the sun, the central heat of the earth, or of artificial fires. It is upon the intensity and quantity of this heat that the elastic force, temperature, density, and volume of the steam obtained for any particular purpose must depend; and it

### *Gay Lussac's Table of the Density and Volume of Steam.*

| Water at 32° being the unit of Density and Volume. | | | | | | | |
|---|---|---|---|---|---|---|---|
| Temperat. | | Density. | Volume. | Temperat. | | Density. | Volume. |
| Fah. | cent. | | | Fahr | cent. | | |
| 32.° | 0° | 0.00000540 | 182323 | 143.6° | 62° | 0.00013760 | 7267 |
| 35.6 | 2 | 609 | 164332 | 147.2 | 64 | 15010 | 6662 |
| 39.2 | 4 | 686 | 145886 | 150.8 | 66 | 16356 | 6114 |
| 42.8 | 6 | 772 | 129587 | 154.4 | 68 | 17797 | 5619 |
| 46.4 | 8 | 869 | 115305 | 158. | 70 | 19355 | 5167 |
| 50.0 | 10 | 974 | 102670 | 161.6 | 72 | 21013 | 4759 |
| 53.6 | 12 | 0.00001092 | 91564 | 165.2 | 74 | 22794 | 4387 |
| 57.2 | 14 | 1224 | 81686 | 168.8 | 76 | 24702 | 4048 |
| 60.8 | 16 | 1372 | 72913 | 172.4 | 78 | 26739 | 3741 |
| 64.4 | 18 | 1534 | 65201 | 176. | 80 | 28889 | 3462 |
| 68. | 20 | 1718 | 58224 | 179.6 | 82 | 31195 | 3206 |
| 71.6 | 22 | 1914 | 52260 | 183.2 | 84 | 33637 | 2973 |
| 75.2 | 24 | 2133 | 46877 | 186.8 | 86 | 36237 | 2760 |
| 78.8 | 26 | 2376 | 42084 | 190.4 | 88 | 38984 | 2565 |
| 82.4 | 28 | 2643 | 37838 | 194. | 90 | 41891 | 2387 |
| 86. | 30 | 2938 | 34041 | 197.6 | 92 | 44956 | 2224 |
| 89.6 | 32 | 3263 | 30650 | 201.2 | 94 | 48201 | 2075 |
| 93.2 | 34 | 3619 | 27636 | 204.8 | 96 | 51613 | 1938 |
| 96.8 | 36 | 4017 | 24897 | 208.4 | 98 | 55191 | 1812 |
| 100.4 | 38 | 4442 | 22513 | 212. | 100 | 58955 | 1696 |
| 104. | 40 | 4916 | 20343 | 250.5 | 121.4 | 0.0011147 | 897.09 |
| 107.6 | 42 | 5418 | 18659 | 275.2 | 135.1 | 16150 | 619.19 |
| 111.2 | 44 | 6023 | 16805 | 293.7 | 145.4 | 20997 | 476.26 |
| 114.8 | 46 | 6585 | 15185 | 307.54 | 153.8 | 25763 | 388.16 |
| 118.4 | 48 | 7242 | 13809 | 320.3 | 160.2 | 30402 | 328.93 |
| 122. | 50 | 7970 | 12546 | 331.9 | 166.5 | 34911 | 286.12 |
| 125.6 | 52 | 8753 | 11424 | 341.7 | 172.1 | 39434 | 253.59 |
| 129.2 | 54 | 9606 | 10410 | 358.8 | 181.6 | 48226 | 207.36 |
| 132.8 | 56 | 0.00010525 | 9501 | 418 4 | 214.7 | 89863 | 111.28 |
| 136.4 | 58 | 11523 | 8680 | 457.1 | 236.2 | 0.0129030 | 77.50 |
| 140. | 60 | 12599 | 7937 | 478.6 | 265.9 | 203060 | 49.315 |

is therefore an important point to determine how it is to be obtained.

The most important and common sources of heat for the production of steam, are the combustion of coal, charcoal, wood, resin, and oil. Many experiments have been made upon the quantities of caloric given out during their combustion; but the results vary much with the methods of applying the heat. The six following are some of the results of Dr Dalton's experiments; the rest are selected from the best authorities:

One lb. of Hydrogen, burnt with 7 lbs. oxygen, produces 8 lbs. of water, and raises 250 lbs. of water 180°.

| | | | |
|---|---|---|---|
| Charcoal, | 2.8 | 3.8 carbon. acid, | 31 lbs. |
| Oil, wax, tallow, | 3.5 | 4.5 water and carb. ac., | 81 |
| Oil of turpentine, | | | 46.4 |
| Carburetted hydrogen, | 4. | 5. water and carb. ac. | 66 |
| Olefiant gas, | 3.5 | 4.5 water and carb. ac. | 67 |
| Naphtha, | 3.20 | | 73 |
| Rape oil, | | | 90 |
| Caking coal, | | | 54 |
| Olive oil, | | | 76 |
| Charcoal, | | | 57 |
| Coke, | | | 51 |
| Peat, | | | 22 |
| Newcastle coal, | | | 55.5 |
| Culm, | | | 11 |

The numbers in the last column represent the number of pounds of water at 32°, which will be heated to 212°, when the fuel is applied in the most economical manner; and hence the quantity of fuel to heat any other quantity of water any number of degrees, can be found by the common arithmetical rules of proportion.

The quantity of water at 212°, which will be converted into steam, may be found, by dividing the number of pounds of water in the table by 5.55. Thus, from the table—

1 lb. of Newcastle coal gives 180° to 55.5 lbs. of water.

Therefore, 1 lb. of Newcastle coal converts into steam, $\left.\right\} \frac{55.5}{5.55} = 10$ lbs. of water.

This is to be taken as the effect that may be produced if there be no material loss of heat; and in the Cornish engines I find that even 10.5 lbs. are actually accomplished.

In general, however, for the purposes of ordinary manufactures, in Lancashire, Staffordshire, and the vicinity of London, it appears that not more than 6.6 lbs. of water are converted into steam by one pound of coal; so that not more than 33.3 lbs. of water are heated with ordinary boilers from 32° to 212°. The following table may be taken as the numbers usually given to represent the actual state of practice. But a late investigation by Mr Parkes shows, that in the best constructions of boilers now used in Cornwall, Warwickshire, and elsewhere, these effects are nearly doubled:

1 lb. of the best coal is generally required to heat 33.3 lbs. of water from 32° to 212°.
1 lb....................6.6 lbs. of water at 212° into steam.
and 1 lb...............5.5 lbs. of water at 32° into steam.
2 lbs. nearly...........one cubic foot of water from 32° to 212°.
11 lbs. nearly.........one cubic foot of water at 212° into steam.
13 lbs. nearly..........one cubic foot of water at 32° into steam.

Now, as a gallon contains ten pounds of water, it follows that—

1 lb. of coal will raise 3⅓ gallons of water from 32° to the boiling point.
5 lbs. of coal will convert 3⅓ gallons of water at 212° into steam.
6 lbs. of coal will convert 3⅓ gallons of water at 32° into steam.

We have given these approximate numbers for practical use, in the application of steam to some of the ordinary purposes and processes of art and domestic use, upon which we are about to enter ; and they are such as may, with very ordinary care, be safely calculated on. But for a full exposition of the processes, and principles, and mechanical arrangements connected with the best methods of generating steam from fuel, we must refer to the article "STEAM-ENGINE," where the generation and condensation of steam find their most important uses.

It may perhaps be proper to remark, that a boiler, which is there called a boiler of one, two, or three horses' power, is one which is capable of raising one, two, or three cubic feet of water into steam in an hour. Whatever, therefore, be the application for which steam is wanted, if twenty cubic feet of water per hour are required to be converted into steam, a twenty horse-power boiler is that which must be procured for the purpose—and of course from 220 to 260 pounds of the best coal will be consumed in that time.

## SECTION V.—THE APPLICATION OF OUR KNOWLEDGE OF THE PROPERTIES, PHENOMENA, AND LAWS OF STEAM TO PRACTICAL AND ECONOMICAL PURPOSES.

1. Warming apartments and buildings by steam. 2. Heating greenhouses, &c., by steam. 3. Evaporating solutions, drying fabrics, paper, gunpowder, grain, &c., by steam. 4. Warming baths, boiling liquids, and distilling by steam. 5. Preparation and economy of wholesome food by steam. 6. The steam-engine.

### 1. *Warming Apartments by Steam.*

66. One of the most important applications of steam

in the economy of fuel, is its employment as a vehicle for transferring to a distance, and distributing uniformly, the heat of a fire for the purpose of warming an apartment or building. Its great efficiency for this purpose arises from the largeness of its capacity for caloric; because, as it holds a quantity of caloric equal to 1000 degrees, it will communicate as much heat as a mass of red hot iron; and it will have this advantage over the iron, that it can carry this heat to a distance without a similar loss; because, the heat being latent, will not be given out until it arrive at its destination and become condensed, when the whole of its 1000° will be usefully applied.

The manner in which warming by steam is to be effected, is this. At a convenient part of the building, and as low as possible, there is to be placed a close steam boiler of the ordinary construction. From this boiler a small steam pipe is to be carried to the part of the building which is to be warmed. This small pipe should be pretty thick, and carefully rolled round with a fillet of flannel to a quarter of an inch thick, and the boiler should be wholly covered with bricks and plastered over to keep it warm. This smaller steam pipe should have an area of one square inch for every six gallons of water that the boiler can boil off in an hour. Pipes of a larger size are to be laid round the room above the floor, or under the floor, if apertures be left to allow a free circulation of warmed air to enter the room; but the best method we have seen is, to make the surbase, which passes round the room, of thin iron plate or copper having the external figure of the surbase, and sufficiently strong to withstand the pressure of the steam, which strong tin plate or copper of 1½ lb. to the foot will sufficiently effect, if the surbase be not more than about 4 inches square.

Into these larger pipes the steam is to be conducted, and in them the steam will be condensed into water, and will give 1000° of heat to the colder air of the room which is in contact with the outside of these pipes. In doing so, the steam being condensed into water, small pipes of lead or tin must be provided, for the purpose of bringing back this condensed water into the boiler; and, in order that they may act well, care is to be taken that a gentle slope, of about an inch in 20 feet, be given to all the pipes. The condensed water being thus conducted back to the bottom of the boiler, it will there be replenished with heat, and in the form of steam will again carry up its supply of 1000° to the apartment, again to be given off as formerly to the room, and then returning once more to the boiler, a continual circulation of the same particles of water, giving out in each circuit a quantity of heat equal to red hot iron, is uniformly and gently imparted to and diffused equally over the apartment. The pipe which brings the steam from the boiler may be called the feeding pipe, the pipes which give off the heat the radiating pipes, and the pipes which lead back the water to the boiler the return pipes. We have already given dimensions for the feed pipe. The return pipes need not be more than $\frac{1}{12}$ of the diameter of the feed pipe, but an increase of size could do little harm, and may have the effect of preventing accidental obstruction: the boiler will require to have a pint of water added now and then to supply accidental waste; and a safety-valve on the boiler is indispensable. A self-regulating feeder, such as that mentioned in the article STEAM-ENGINE, among the apparatus of boilers, is also to be recomended where it can be readily attained. It is necessary, however, to give directions at greater length for the dimensions of the warming or radiating pipes, as it is upon their proper construction and arrangement that the efficiency of the apparatus entirely depends; and the apparatus has frequently failed from the want of proper precaution. The radiating pipes in the room are generally too small. It is their extent of surface, and the free circulation of air round them, which determines how much of the heat will be given out, and how rapidly, From very accurate experiments I am induced to conclude that a room containing 500 cubic feet of air, and exposing 400 feet of surface, may be maintained at a temperature of 20° above that of the air without—that is to say, at 60° in the inside of the room when the atmosphere is at 40° without—for a space of twelve hours, by the evaporation of 2 gallons of water, and at the expense of about three pounds of coal of the value of one farthing. But this supposes that there is no ventilation, and that the air of the room is never changed; whereas, the presence of one individual would render it necessary to introduce nearly 400 cubic feet of external air every hour. Now, the heat of 20° given to 400 cubic feet of air would require the evaporation of 3 gallons of water; and, therefore, the evaporation of 3 gallons of water would be required for such a room, and 3 gallons for every person in it, if properly ventilated, and for every 2 gallons there should be at least one square foot of radiating surface; so that such a room, occupied by one person, would require a surface of warming pipe equal to 2½ square feet, and so on for every such room and occupant, for a space of 12 hours in the day.

Thus, the evaporation of 1 gallon per day for every 400 feet of surface, with a difference of temperature of 20°

from the external air, and 1½ gallons per day for each person, and 1 square foot of radiating surface, is a standard from which we easily calculate.

A room 30 feet long, 20 feet wide, and 10 feet high, has a surface of 2200 feet, which would require 5½ gallons; six people would require 9 gallons; therefore, 14½ gallons of water and 7¼ feet of radiating surface will heat the well-ventilated room 12 hours for 6 persons at an expense of 25 lbs. of coal, or about threepence per day; or a whole house, occupied by 6 persons, may be warmed, if 30 feet high, 30 feet wide, and 30 feet deep, at tenpence a-day, the price of coals being twenty shillings a-ton.

It is scarcely necessary to add, that the radiating pipes may be best constructed of thin copper, and ought to be roughened and blackened on the outside.

In the same way the calculation may be made for any other room, building, and number of occupants.

For more extensive and minute information on the subject of warming, the reader is requested to consult the article "WARMING AND VENTILATION," in the Encyclopædia.

The form in which the radiating surface may be distributed admits of variety.

Provision must be made for the expansion and contraction of the pipes.

The arrangement of steam in the apartment to be heated is of some consequence. It is, we have already stated, sufficiently out of the way in the surbase, but, in that case, much heat passes out into the walls and wood. It may stand on the hearth like a stove, and consist of concentric cylindric chests within each other (fig. 24), filled with steam, and allowing air to ascend by the sides

Fig. 24

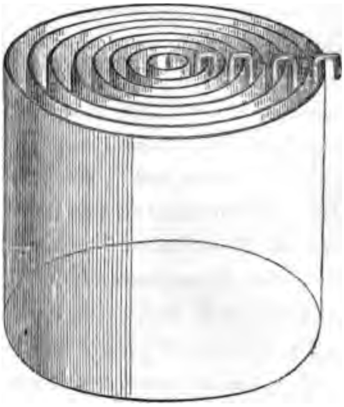
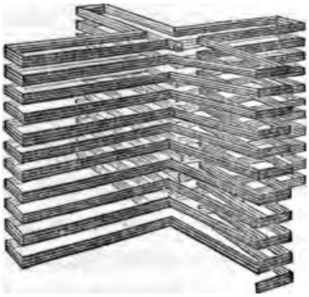


Fig. 25.



and through the intervening spaces, so as to be made warm, and the outer surface radiating directly on the surface exposed. It may be tubular, and coiled in a large quantity in a small box fitted up externally in the appearance of a cabinet or pedestal in the apartment, thus: (Figs. 25 and 26); the feed pipe commencing at the top of the coils, and the return pipe passing off from the bottom. As the conducting power of tin is nearly equal to that of iron, a quantity of tin pipe will suffice, and be more economical than iron or copper. This coil may be placed in a cabinet or pedestal of the form of Fig. 26, and the warm air will have free egress through the wire-work of the panel.

The next diagram (Fig. 27,) shows an arrangement of copper steam-vessels, by which an extensive surface is very efficiently exposed to the air, the condensed water being drawn off at the bottom.

There is one case in which warming by steam may

Fig. 26.

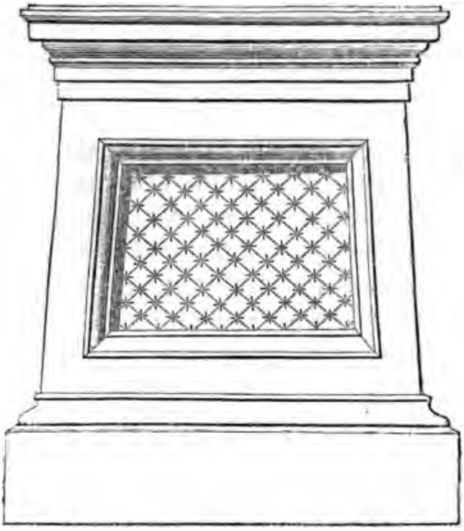
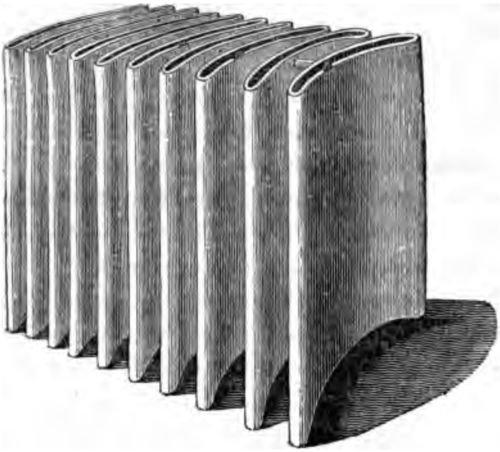


Fig. 27.



be employed with especial advantage, and where it is frequently neglected—where the power of steam is already employed to drive machinery. Let the engine employed be what is called high-pressure, or non-condensing, in which the steam escapes from the engine and is passed off into the air; and, instead of the common plan, let the steam from the engine be conveyed in pipes through the apartments to be warmed, and let the diameter of the pipe gradually increase towards the end of its circuit, and finally terminate in a hot-water pipe, which may also circulate in the building, and there will be given out the whole original heat of the steam after having done its work in the steam-engine, and that as effectually as if there had been no steam-engine at all, and the whole power of the engine will thus be clear saving. This will be the case to a still greater extent if the steam-engine work expansively, and may further be increased if the pipes be so formed as to constitute an aerial condenser. For further information on this subject see article STEAM-ENGINE.

### 2. *Warming Hothouses, Greenhouses, &c., by Steam.*

67. The principles which regulate this application of steam are similar to those mentioned already in Art. 66, and steam possesses the same advantages in the distribution of heat for this purpose, which it does in the cases already mentioned. The warmth thus distributed is freed from those risks of injury to the vitality of the plants, which accompany the old method of warming by hot air flues, in which a contaminated and unwholesomely dry air and unequable temperature were inevitably produced, and an occasional annoyance from smoke. The warmth given out by the steam is of uniform intensity throughout the

whole length of the glass; it occupies very small space —one furnace and chimney is all that is required for any extent of range of glasshouses, as the steam may be conveyed to any usual distance in well swathed pipes without sensible loss. The saving thus effected by the concentration of the fire, and by its equable distribution, has been found to produce an economy of more than one-third of the fuel commonly used. At Sion House, the seat of the Duke of Northumberland, there are nearly a thousand feet in length of glasshouses heated by one such apparatus. The boiler and chimney may also be placed at a convenient distance from the houses—a circumstance which contributes much to the beauty of this arrangement.

Those who wish to study the details of this subject are referred to Mr Loudon's Horticultural Works, and to the article "HORTICULTURE," in the Encyclopædia. The following are the mechanical principles and arrangements that belong exclusively to this article.

Our first subject of enquiry, is into the amount of heat requisite to sustain the glass at a given temperature higher than that of the external air; if we take the temperature of the atmosphere at 35°, and that of the hothouse at 65°, giving 30° of difference, we shall have a case approaching near to that of a glasshouse in winter. In order to determine this question, which can only be ascertained by experiment, the author has examined a case upon a large scale, which may furnish a standard of comparison.

The large palm-house of the Botanic Garden of Edinburgh is an octagonal structure, 60 feet in diameter, and 45 feet high. Excepting stone pillars at the angles, and between the windows, of about three feet wide, the whole building is glass, presenting a surface of almost exactly 5000 square feet of glass. The quantity of fuel required in a cold atmosphere, having a mean of 35°, is 1344 pounds for 24 hours; being at the rate of 269 lbs. of coal for every 1000 feet of glass in a day, or 11.2 pounds an hour for 1000 feet, or .0112 of a pound per hour for each foot.

To confirm this observation, it was thought proper to examine another house of different dimensions. The eastern wing of the great range of houses is warmed by a fire, which consumes half that quantity of coals, of about half the value, being dross of a bad quality; so that its consumption is about ¼ of the other in real value, being about 672 lbs. of dross, equivalent to 336 lbs. of good coal in 24 hours. Now, the exposed glass of this wing amounts to about 1376 square feet, being at the rate of 243 lbs. to 1000 feet—a result which is sufficiently near to the other, to allow us to assume 250 or 260 lbs. of fuel in 24 hours for each thousand feet, as a standard of tolerable accuracy in such cases. It may be useful to add, that these houses are in tolerably sheltered situations, and that the glass faces in every direction, so as to be acted on with tolerable uniformity.

Hence we have the following results:

Temperature of the air 35°—temperature of the hot-house 65°.

Heat sustained 24 hours, by 250 lbs. of good coal, for 1000 square feet of glass.

Heat sustained 1 hour, by 10.4 lbs. of good coal for 1000 feet of glass.

Heat sustained 1 hour, by 0.0104 lbs. of good coal, for one foot of glass.

To find what amount of steam will be required to warm such a house, we have only to apply the calculations of Art. 66; 10.4 lbs. of good coal will convert seven gallons of water into steam; therefore, a boiler of one horse's power is necessary to evaporate a sufficient quantity of water for the supply of steam for each 1000 feet of glass; that is to say, for the palm-house alone, a boiler of five horses' power would be required to furnish steam; and this supposes the hot water of the condensed steam to be returned into the boiler immediately; and if this were not the case, six horses' power would be the size of boiler ordered for this purpose: hence—

To warm a hothouse by steam, there is required the boiler of a steam-engine, reckoned at one horse's power for every thousand feet of glass.

The method of distributing the heat through the rooms of the hothouse, is not a matter of so nice calculation as in a common apartment. There is much greater convenience for this purpose in a greenhouse than a common room, on account of the necessary vacuities under the ranges and beds. In general, a single circuit of steam-pipe four inches in diameter, round the apartment, with a return pipe of equal dimensions laid parallel to it, is sufficient.

It is, however, of great importance to provide a remedy for one of the practical inconveniences of steam. When the fire is not very carefully tended, as during the night, the steam in the boiler falls below the proper point, and the supply instantly ceases. This is remedied by the following method. Cast iron boxes, a foot square and five or six feet deep, are filled with stones, and ranged round the forcing rooms—a pipe passing into each of them communicates a supply of steam to them, and the stones they contain. The caloric entering first of all with rapidity into the stones, is afterwards given out gradually by them to the house; and the advantage of this arrangement is, that even if neglect or accident were to occasion a temporary cessation of the supply, this heat would still continue to be given out from the matter of the boxes for several hours, until the defect might be remedied. These boxes of stones perform the same function for caloric that a fly-wheel does for mechanical power—absorbing it when in excess, and giving it out again when deficient.

It is a valuable hint to economy, which Mr Macnab has put in execution in his houses at the Botanical Garden, that the boiler flues should be extended to the greenhouse after they have left the boiler; the remaining heat is thus given out to the hothouse, and the last degree of saving accomplished. With this arrangement a smaller boiler will suffice; but it will not always be convenient, neither can a greater length than about 30 feet of flue be advantageously used in this way.

### 3. *On Evaporating and Drying Solutions, Cloths, Paper, Grain, Gunpowder, &c., by Steam.*

68. We have already observed how well the peculiarities of steam enables us to make use of it as a vehicle for the collection, transference, and distribution of heat. In addition to the facility with which it may be carried to a distance, and the uniformity of temperature resulting from it, we have this further adaptation to the purposes now under consideration, that the temperature can at no time become so great as to produce injury, or deteriorate the substances to which it is applied. Hence it follows that thickened liquids, strong solutions, and any porous solid matter impregnated with fluid may be evaporated.

and wholly separated from the fluid, without incurring the danger and suffering the deterioration resulting from direct application of the fire. And, further, by the proper application of steam, as a conductor of heat, liquids may be warmed, evaporated, and even boiled in vessels of wood, which is in some cases, as in brewing and delicate distributions, a matter of much importance.

When any mixture or solution of a solid in water is to be evaporated by steam, it may be done in some of the following ways.

(1.) The vessel containing the solution may have two bottoms, the interval between them being filled with water and steam, and the solution resting on the upper one, the fire is applied to the under one; thus the steam and water intervening between the solution and the fire, the latter is protected, as well as the vessel itself, from being burned when the process has nearly attained the necessary degree of dryness; and the process of communicating the heat from the fire to the water takes place in the following manner; the fire generates in the water bubbles of steam, which ascend from the lower to the higher bottom of the vessel, which is in contact with the solution and acquires its temperature, and, giving off their heat to the upper bottom, are condensed, and fall down again to the lower bottom to acquire the accession necessary to rise, once more, in steam to the top. This plan has been successfully used in making salt; and it is necessary to have a safety and an atmospheric valve attached to the space between the lower and upper bottoms. The quantity of heat required for the purpose of evaporating the water of the mixture is neither increased sensibly, nor diminished by the intervention of the steam between the bottoms ; the number of gallons of water to be evaporated from the solution will determine the quantity of heat by Art. 66.

(2.) A second method of producing evaporation is to introduce among the mixture a steam pipe, so as to wind amongst it either in the form of a helix, like a cork-screw or worm of a still, or to perform such a circuit as shall expose a large quantity of surface, with tolerable uniformity, to the fluid for the absorption of heat from the steam. Copper is the best material for the tubes, and wooden tanks lined with lead or tin will contain the mixture. The fuel required for evaporation will be 5 lbs. for every 3⅓ gallons of water to be evaporated, and the steam boiler must have one horse's power for every 6 gallons to be evaporated in an hour.

(3.) A third method is the invention of Mr Goodlet of Leith. The substance to be evaporated is forced by means of a pump into a long copper pipe, which enters a close steam boiler, and after winding through it so frequently as to expose a sufficient surface for a sufficient length of time to acquire the necessary supply of heat from the boiler, again passes out from the boiler and discharges its heated contents into an appropriate reservoir, again, if necessary, to be passed once more through the same process by the force pump. In this case the substance is brought to the steam boiler for evaporation instead of having the steam brought to it, and thus any loss of heat during the transit of the steam is prevented.

A steam kiln for drying grain has been used with great success by the same person. The grain is spread out on the iron floor of a large room—this floor is perforated with a multitude of small openings, or formed of a very fine grating; immediately under the floor steam pipes of 6 inches diameter lie parallel to each other at small intervals apart, and radiate heat directly to the floor and the grain, and also to the surrounding air, which in this hot state ascends through the grain; numerous large ventilators being provided for the escape of the vapour thus impregnated with moisture, after it has ascended through the grain. This method has been found effectual, and is attended with less risk of injury than the ordinary one.

In the processes of drying and printing cloths and fabrics of various kinds, rapid and complete drying is of much importance. This is effected principally in what is called a drying frame: this consists of a dozen of tin cylinders, a foot in diameter and 6 or 8 feet long; these cylinders are closed completely by two hemispherical ends, and are placed upon an axis in a frame, so as to revolve in contact with each other. Steam is conducted into all these cylinders by a pipe passing through the axis, which is hollow, and the joint is made steam-tight by a stuffing-box similar to that of the cover of a steam-engine cylinder. A piece of cloth dripping from the dye-vat is passed through the frame once and is then perfectly dry. Of course, the quantity of steam required for this process is proportional to the number of pounds of water to be evaporated from each piece, that is, to the difference between the weight of a piece when wet and when dry. The number of lbs. being ascertained, the fuel and power of the boiler are found from article 66.

In the manufacture of paper the process of drying by steam is beautifully exhibited. The wet pulp, laid out on the web of wire cloth, is gradually strained as it approaches the large hollow cylinders, around which it winds for half a minute and then comes off perfectly dry finished paper, ready for use. This process is minutely described in the article "PAPER" of the Encyclopædia.

### 4. *Warming Baths, Boiling Liquids, Distilling by Steam.*

69. To heat water rapidly, and in considerable quantity, by means of a fire placed at some distance, is a problem frequently proposed; and steam for such a case is an excellent vehicle for the heat. Let there be placed in a steam boiler 10 gallons of water, and heated into steam; these 10 gallons conveyed to a reservoir or bath of water at a distance, by a small lead pipe, will heat nearly 55 gallons of water from 32° to the boiling point, or 165 gallons from 40° to 100°, the usual temperature of a warm bath. A bath of the ordinary construction will require about 160 gallons, and the said 10 gallons will require 18 lbs. of coal, value sixpence. Besides this, the sides of the bath, if made hollow, may be warmed by the introduction of steam between the lining and the outside, at the same time that the water is warmed; and the apartment may further be heated with steam pipes from the same apparatus.

The most effectual method of communicating the heat of steam to water, is to pass the open end of the steam pipe from the boiler directly into the water to be heated, so as at once to mix with it. The mouth of the pipe, properly regulated by a stopcock, should enter at the bottom, and be directed from one end of the bath along one side towards the other, and thus the impetus of the steam on entering will communicate to the water a circulation highly conducive to an equable distribution of heat.

A very simple apparatus of this kind may be placed in the same apartment with the bath itself. A boiler 4 feet long and 2 feet deep, with a fire covering a square of 18 inches, will heat such a bath in three quarters of an hour. A copper boiler will be most effective, and the steam pipe should first be matted with bandages of flannel, and then stitched with canvass painted, from the boiler to where it enters the bath.

In establishments where there are many baths, a reservoir at the top of the building may be kept constantly filled with water ready to descend into the baths, the reservoir being supplied with heat from the steam pipe of a boiler placed in the outer buildings, or some other suitable place. It is to be recollected that the boiler used must be what is called a one, two, or three horse power boiler, according as one hundred, two hundred, or three hundred gallons per hour are wanted; and so on for every additional hundred gallons of water at 100° of temperature—one horse power of boiler for one hundred gallons.

The same process may be used for heating and even for boiling a liquid or solution, in which no injury will result from adding the steam of this condensed water to the liquid. In a dye-work, or other work where much boiling and many solutions are used, steam boiling in this manner is a process of great convenience and value. The vessels containing dyes of various kinds, including leys and solutions of various substances, in which cloths, yarns, wools, and various materials are to be boiled, are ranged around a spacious apartment. Around this apartment, attached to the wall, circulates a steam pipe of two inches diameter, from which smaller branch pipes go off to each of the boilers from the nearest point, and pass down to the bottom of their respective vessels. The exit of the steam is governed by a stopcock under the hand of the operator; and by this means he can easily, by allowing a smaller or greater supply of steam to enter the liquid, produce a uniform and gentle simmer or excite an instantaneous and tumultuous ebullition. Two great advantages give this method much superiority over the common mode of boiling by the direct action of the fire. The condensed steam supplies to the solution exactly as much water as is lost by evaporation, so that it remains of the same strength through a protracted process, and there is no injury sustained by allowing the substances immersed to settle down and rest at the bottom.

Where it is not allowable for the caloriferous steam to be condensed in contact with the liquid to be warmed or boiled, we must resort to the method of heating by surface; that is to say, the steam must be conveyed through the mass of liquid by a pipe, or other conductor best fitted to give out the heat or retain the water. A very thin pipe of the purest soft copper is best for this purpose; 2 inches in diameter and $\frac{1}{20}$ to $\frac{1}{40}$ of an inch in thickness will be found good dimensions, and a square foot of surface for every 10 gallons of water to be boiled per hour will be required. For some purposes, it will be enough to wind the pipe in a spiral round the inside of the vessel to be heated; but if the vessel be large, numerous pipes must pass through the liquid. For boiling 1000 gallons per hour, 200 feet of copper pipe 2 inches in diameter are required.

In distillation by steam, the same method of communicating heat to the liquid to be distilled is employed as already described in boiling. But the vapours of other liquids having less specific caloric than water, a smaller quantity of steam from the boiler will be required to evaporate them than to evaporate an equal quantity of water; thus the heat of 1 gallon of water will evaporate and cause to be distilled 2 gallons of alcohol, 3 of sulphuric ether, and 4 of turpentine. It is a curious phenomenon, of which distillers should avail themselves in carrying off the vapour in distillation, that although alcohol floats on water, and ether on alcohol, nevertheless the vapour of water floats above vapour of alcohol, and vapour of alcohol above vapour of ether.

| The densities of | water, | alcohol, | and ether |
|---|---|---|---|
| being | 10. | 8. | 7. |
| and the densities of their vapours | 6. | 16. | 25. |

in round numbers.

### 5 *Preparation of Food by Steam.*

70. The last of the applications of steam which we shall here examine is that which was historically the first, its application to cooking and other domestic uses. This invention makes its appearance in the following record of the Royal Society of London.

At a meeting of the Council of the Royal Society,
December 8, 1680.

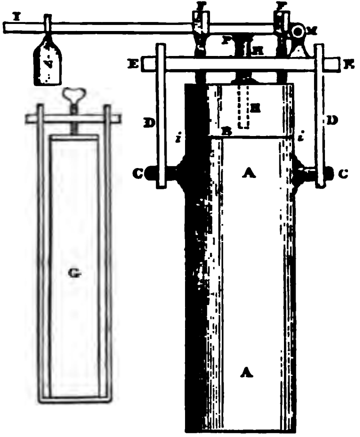
Ordered, that a book intituled A New Digestor, or Engine for softening Bones, &c., written by Denys Papin, Doctor of Physick, and Fellow of this Society, be printed and published. CHR. WREN.

This work on the New Digester was accordingly published in 1681; "Containing the description of its make and use in these particulars, viz., Cookery, Voyages at Sea, Confectionary, Making of Drinks, Chymistry and Dyeing, with an Account of the Price a good big Engine will cost, and of the profit it will afford."

The following list will show the extent to which the learned doctor had proceeded in applying steam to the improvement of the dietetic art. It is copied from the Index to the work. " (1.) How to know the quantity of pressure in the Digestor. (2.) How to know the degree of heat. (3.) How meat may be kept upon the fire three times as long as is necessary to make it ready, and yet it will not be spoiled. (4.) The same experiment made upon bones. (5.) How to boil mutton. (6.) How to boil beef. (7.) How to boil lamb. (8.) How to boil rabbits. (9.) How to boil pigeons. (10.) How to boil fish. (11.) How to boil pulse. (12.) How to make jelly, very cheap. (13.) Glue for glasses. (14.) Hartshorn turned like Parmesan cheese. (15.) A macquerel kept without salt. (16.) Salt water as good for nourishment as fresh water. (17.) To make sweetmeats at a cheap rate, and of a new taste. (18.) To make two sorts of drink with the same fruit. (19.) To make a new sort of wine. (20.) Tinctures drawn in the hundredth part of the time usually required for them. (21.) New ways for distilling. (22.) How to hatch chickens. (23.) How to save the labour of grinding cochenille. (24.) To dye with thick juices. (25.) To make horn and tortoiseshell soft for a great while."

This catalogue of uses of steam we shall shortly run over, as the modern uses of steam for cookery are principally applications of Dr Papin's methods; and as valuable economization in the preparation of food on a large scale has resulted from them, especially in the extraction of highly nutritious food from bones. A digester on the principle of Dr Papin's is used in every modern kitchen. "Description of the Digester and how to use it safely."

Fig. 28.



"A A is a brass (or copper) cylinder, hollow within, shut at the bottom and open at the top. B is another cylinder inverted upon it. C C are two appendices or ears cast to the cylinder A A, as the trunnions of a piece of ordnance. D D are two pieces of iron put upon the appendices at one end, and the iron bar E E at the other. F F are two screws, which serve to press both the cylinders A A, B B, against one another. G is another hollow cylinder, made of glass, pewter, or some other materials, fitted to receive those things that are to be included in the cylinders A A, and B B, with water all round it.

"To use this engine with convenience and ease, it ought to be fitted in a furnace built on purpose for it, and should go on as far as the appendices C C; so the fire being underneath, and the screws well fastened, and a piece of moistened paper laid between the cylinders at the joint *i i* to make it steam tight, you may boil your meat as long as you please without danger of wasting it by the exhalation of the volatile parts.

"To know the quantity of the inward pressure, you must have a little pipe open at both ends as H H: this being soldered to a hole in the cover B B, is to be stopped at the top with a little valve P, exactly ground to it. This must be kept down with an iron rod I M, one end of which must be put into an iron staple M, fastened to the bar E E, and the other end kept down by a weight N to be hung upon it nearer or further from the valve according as you would keep it less or more strong, after the manner of an ordinary Roman balance, or steelyard.

"To know the degree of heat, I hang a weight to a thread about 3 feet long, and I let fall a drop of water into a little cavity made for that purpose at the top of it, and I tell how many times the hanging weight will move to and fro before the drop of water is quite evaporated.

"*Experiment.* Having filled my pot with a piece of a breast of mutton, and weighed five ounces of coals, I lighted my fire, and by blowing gave such a heat that a drop of water would evaporate in 4 seconds, the inward pressure being about 10 times stronger than the atmosphere: I let the fire go out of itself, and then the mutton was very well done, *the bones soft* and the juice a strong jelly. So that, having had occasion to boil mutton several times since, I have always observed the same rule, and never have missed to have it in the same condition, which I take to be best of all."

Beef required 7 ounces of coal and the same heat, and the beef was very well boiled, although there were more parts of the bones not quite softened. Lamb, rabbits, and pigeons, mackerel, pike, and eel, were subjected to the same process; whence the doctor infers that the bones of young beasts require almost as much fire as those of old ones to be boiled, that rabbit bones are harder than those of mutton, that tough old rabbits may be made as good as tender young ones by this means, that pigeons may be best boiled with a heat that evaporates a drop of water in 5 seconds, that mackerel was cooked with gooseberries in a digester, the fish being good and firm, and the bones so soft as not to be felt in eating; and he particularly recommends, as an excellent dish cooked in this manner, cod fish and green peas.

The most important of Papin's experiments are those on the extraction of gelatine from bones, as now done on a large scale in France and in this country, as also the manufacture of essence of meat, soups, &c., especially suitable for long sea voyages.

"I took," says he, "beef bones that had never been boiled, but kept dry a long time, and of the hardest part of the leg; these being put into a little glass pot with water, I included in the engine, together with another little glass pot full with bones and water too, but in this the bones were ribs and had been boiled already. Having prest the fire till the drop of water would dry away in three seconds, and ten pressures, I took off the fire; and the vessels being cooled, I found very good jelly in both my pots; but that which had been made out of ribs had a kind of a reddish colour, which I believe might proceed from the medullary part, the other jelly was without colour like hartshorn jelly; and I may say, that having seasoned it with sugar and juice of lemon, I did eat it with as much pleasure, and found it as stomachical, as if it had been jelly of hartshorn." Mutton bones are better than beef bones; and he infers (1.) that one pound of beef bones afford about two lbs. of jelly; (2.) that it is the cement (gelatine) that unites the parts of the bones, which is dissolved in the water to make it a jelly, since after that, the bones remain brittle; (3.) that few glutinous parts are sufficient to congeal much water, "for I found that when the jelly was dried, I had very little glue [-ten?] remaining; (4.) I used it to glue a broken glass, which did since that time hold very well, and can be washed as well as if it had never been broken; (5.) it is heavier than water, and sinks to the bottom; (6.) hartshorn produces five times its weight of jelly.

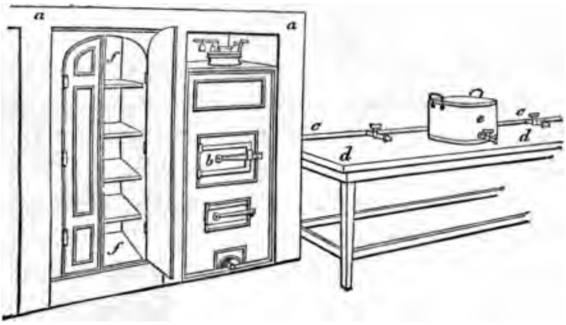
"From all these experiments, I think it very likely, that if people would be persuaded to lay bye bones, gristles, tendons, feet, and other parts of animals that are solid enough to be kept without salt, whereof people throw away more than would be necessary to supply all the ships that England hath at sea, the ships might always be furnished with better and cheaper victuals than they use to have. And I may say, that such victuals would take up less room too, because they have a great deal more nourishment in them in proportion to their weight. They would also be more wholesome than salt meat. Vegetables, such as dried peas, may also be cooked by the steam of salt water without becoming salt."

We have entered thus fully upon the work of Doctor Denys Papin, and the properties of his digester for cooking, and extracting jellies by high-pressure steam, because it contains nearly all that is at present practised in the preparation of food by steam.

If to what has been already stated, we add, that if the steam of salt water be collected in a vessel kept cold on the outside, the condensed water will not be impregnated with salt, and may be used as food, the importance of steam in the economical and menial capacity of cook, will be sufficiently apparent. The supply of water to the crew of a steam vessel may be obtained in this manner, and an apparatus for thus procuring fresh water from the condensation of steam from salt water, has been used with advantage in ordinary ships.

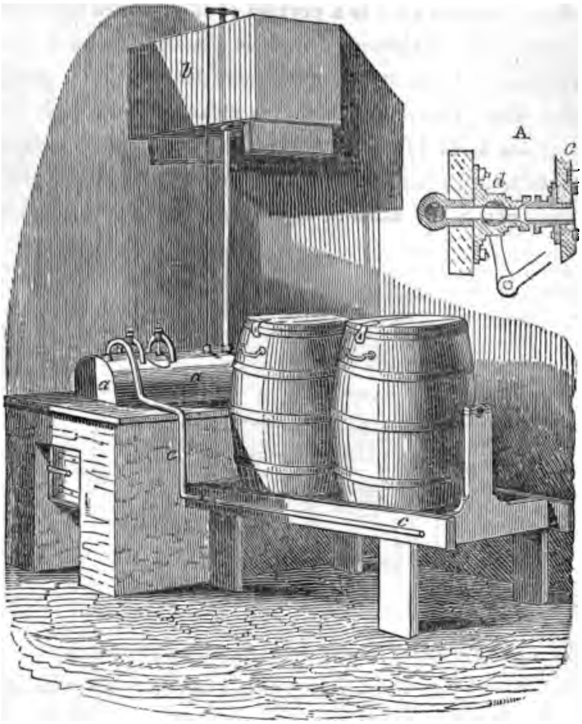
Fig. 29 contains the steam-cooking apparatus used in modern kitchens ; *a a* is a portion of the kitchen fireplace. In one of the divisions of it, *b*, is placed a steam boiler, furnished with the usual apparatus of feeding pipes, gauge cocks, &c. From this boiler a steam pipe, *c c*, is led along the back of the cooking table *d d*, and at certain intervals, branch pipes, furnished each with a stopcock, project across the table at right angles to the main pipe.

Fig. 29.



The extremities of these branch pipes are conical, and made accurately to fit into conical sockets inserted into the cooking pans, one of which, *e*, is seen in its place on the table. These pans have each a double bottom, the lower one close, the upper one perforated ; between the bottoms the socket before mentioned, through which the steam enters, is inserted. The manner of using this apparatus is simple. The article to be cooked is laid in its place on the perforated bottom of the pan, the lid is applied, and the pan is joined to one or other of the branch pipes, by its socket receiving the conical end

Fig. 30.



of the pipe; the stopcock is now turned, and the matter in the pan is subjected to the action of the steam. Each pan has a crane in front, to allow of the condensed steam being drawn off.

The remaining part of the apparatus is the hot closet *ff*. This consists of a steam-tight iron box, containing shelves, inserted in another iron box of dimensions so much greater as to allow of a considerable vacuity being between them; into this vacuity the steam from the boiler is permitted to flow, and give out its heat to the articles placed in the closet to receive it.

Fig. 30 contains a steam-apparatus for cooking the food of cattle and horses, designed by Mr Newlands of Edinburgh. *a a* is a steam boiler, furnished with man-hole, safety-valve, gauge-cocks, supply pipe, and regulating float; *b*, a water cistern, placed not less than six feet above the boiler; *c c*, the steam pipe proceeding from the boiler, and extending along the front of the gauntree for supporting the casks or other vessels in which the food is held. These vessels are hung on pivots, between the uprights, (of which one is seen in the drawing,) in such a manner as to throw the centre of gravity a little below the points of support; and each vessel has a false bottom pierced with many holes, and fixed a few inches above the true bottom. When the contents of a vessel are to be discharged, the superintendent lays hold of the handle, seen in the front, and, by a little force, turns the vessel round its axis, until its front lip rest on the front bar of the gauntree, which is placed so low as again to throw the centre of gravity of the vessel below the points of support; the contents may then be emptied into a close barrow, or other suitable vessel, or into a trough extending along the front of the gauntree.

The manner of connecting the vessels with the steam-pipe remains to be noticed. From the main pipe *c*, branches are carried through the front bar of the framing opposite to the centre of every vessel, of which there may be many, although two only are represented. Fig. A exhibits a section of the main pipe, the branch pipe, and a part of the bottom of the vessel. The branch pipe *d* terminates in a conical socket, and into this the plug fixed on the vessel *c* is fitted. When the vessel is in a vertical position, the connexion between it and the boiler is complete; but when, in being emptied, the vessel is overturned, the plug is withdrawn from the socket, and the communication cut off. When the vessel is again restored to its vertical position, the parts again fit each other without trouble or care on the part of the attendant. The branch pipe is moreover furnished with a stop-cock, the handle of which is wrought by a rod from either an eccentric or a crank fixed to one of the pivots of the vessel. When the vessel is overturned and the plug withdrawn, the eccentric shuts the stopcock, and prevents the steam from escaping, re-opening it when the vessel regains its vertical position.

# STEAM NAVIGATION.

None of the diversified and important applications of the steam-engine seems to be more curious or valuable than the navigation of ships against opposing winds and currents—and in none of its applications does the steam-engine seem destined to occupy a position so imposing, as when engaged in effecting a safe, rapid, and certain communication between provinces, nations, and continents.

We are placed in that interesting epoch of time, when steam-navigation is becoming an element, in the destiny of the human race, more important than any art or invention of which we possess the records, if we except, it may be, the art of printing. The whole surface of our globe is now being rapidly encircled by a network of lines of communication by steam. The widest ocean forms no longer a gulf of severance between the divided races of the human family, but the waves alike of the Atlantic and Pacific bear along unharmed on their heaving billows, those trusty and indefatigable messengers of peace, amity, and civilization. Ere a few more years pass over our heads, there will scarce remain a speck of earth tenanted by our fellow-men, which will not have been linked to the great centres of civilization by a steam communication. Already have those great moral, as well as physical deserts of Africa been explored by steam; already has the steamship threaded the mazes of the Pacific, laid open the wilds of New Holland, wound along the fertile valleys of Hindostan, and broken the silence of the vast solitudes around the Huron and the Erie; and scarce a lake that gems the summits of the Alps, whose deep blue basin is not whitened by the foaming paddle and the crested prow. Diligent, faithful, untiring servants of the human race, steam ships are now disseminating to every clime the natural productions, the manufactures, the luxuries, the arts, the civilization, the literature, the science, and the religion of the most favoured parts of the earth. Nations comparatively strangers, are now brought into intimate communication; people formerly enemies, are daily becoming reconciled, and reciprocating those kindly feelings which the consciousness of mutual wants and the interchange of mutual benefits are sure to engender and mature; thus national prejudices and antipathies are rapidly wearing away; and those who watch with care the progress of the human race, and extend their philosophic regards beyond the sphere of ordinary observation, see plainly in the rapid and wide extension of steam navigation, a mighty power at work for the reunion in the bonds of eternal friendship of all the severed branches of the human family, and for the universal reign of order and liberty, peace and concord, science and religion.

To Great Britain, the art of steam navigation has been of peculiar importance. Her insular position and indented coasts, have demanded of her the sedulous cultivation of a vehicle so well adapted to mercantile communication. Her mineral wealth, and her mechanical resources, have peculiarly fitted her for its adoption, extension, and improvement. And the existence of our immense and valuable and wide spread colonial empire, is now inducing the government of Great Britain to draw more closely around her those children of her soil, those feeders of her wealth, those consumers of her industry, by the most gigantic system of colonial steam communication which has ever been conceived, and which is, in part, already executed, and is now in rapid extension. And, lastly, if it be possible that enlightened and civilized nations can be supposed capable of ever again perpetrating the atrocities of mutual war, steam navigation will become to Great Britain the most valuable of her defences, and one in which she will possess that unquestioned supremacy which she has always wielded in the cause of order, liberty, and peace.

It is astonishing with what rapidity the extension of steam navigation has taken place in this country. As a practical art, it is hardly a quarter of a century since navigation by steam was introduced. The following statement by her Majesty's Commissioners on steam navigation, will show the amount of capital and enterprize already directed into this new channel:—

The total number of British and Irish steam-vessels, including those registered in Guernsey, Jersey, and Man, amounts to 766 ; of these 484 may be considered as river steamers, and small coasters ; and 282 as large coasters, and sea-going ships.

The increase in 1837 over 1836, was 78; and that of 1838 over 1837, 59 registered vessels.

## *A Statement of the Approximate Number, Tonnage and Power of Vessels belonging to the Mercantile Steam-marine of the United Kingdom and its Dependencies.*

END of YEAR 1838.

| | Number of Vessels per Custom-house Return, 1838. | Size of Vessels per Custom-house Return. | Registered Tonnage, | Tonnage of Engine-Room, &c., not registered at the Custom-house. | Total computed Tonnage. | Computed Amount of Horse-power. | Computed Power per Vessel. | Total computed Tonnage per Vessel. |
|---|---|---|---|---|---|---|---|---|
| | No. | Tons. | Tons. | Tons. | Tons. | Horse power. | Horse-power. | Tons |
| | 256 | below 50 | 6,106 | 10,816 | 16,922 | 6,400 | 25 | 66 |
| | 145 | 50 to 100 | 10,267 | 7,458 | 17,725 | 6,866 | 47 | 122 |
| | 84 | 100 to 150 | 10,034 | 7,761 | 17,795 | 7,483 | 90 | 211 |
| | 63 | 150 to 200 | 10,982 | 7,147 | 18,129 | 7,560 | 120 | 287 |
| | 76 | 200 to 300 | 16,654 | 10,839 | 27,493 | 11,188 | 147 | 361 |
| | 41 | 300 to 400 | 14,247 | 7,580 | 21,827 | 10.914 | 266 | 532 |
| | 10 | 400 to 600 | 4,488 | 3,506 | 7,994 | 3,000 | 300 | 769 |
| | 1 | 679 | 679 | 661 | 1,340 | 450 | 450 | 1,340 |
| | 1 | 10,53 | 1,053 | 810 | 1,855 | 500 | 500 | 1,855 |
| Vessels registered, 1838, | *677 | - - | 74,510 | 56,578 | 131,080 | 54,361 | — | — |
| Not registered, - - | 83 | - - | 4,154 | 5,484 | 9,638 | 2,129 | 50 | 116 |
| Total in Great Britain and Ireland, 1838, - | 760 | - - | 78,664 | 62,062 | 140,718 | 56,490 | — | — |
| Guernsey, Jersey and Man, 1837, - - | † 6 | - - | 832 | 618 | 1,450 | 600 | 100 | 241 |
| British Plantations, 1837, | †44 | - - | 8,411 | 7,253 | 15,664 | 6,160 | 140 | 350 |
| Grand Total, | 810 | - - | 87,907 | 69,933 | 157,840 | 63,250 | — | — |

* The Custom-house Return enumerates 678 steam-vessels; but the tonnage of one—burnt—is omitted.

† These are extracted from Mr Porter's Returns, as we have not received them for 1838.

Since this statement was published, and while this article is passing through the press, there are being prepared for sea, besides the usual additions to the same navy of vessels of a smaller class, a fleet of 20 ocean steamers, of from 1200 to 1400 tons, and 400 to 500 horse power—the property of British merchants receiving encouragement from our government. The amount of capital thus afloat in steam ships, is from *five to six millions.*

The steam communication of America has made strides equally gigantic, in a direction different from that of Great Britain, but equally accordant with her political circumstances and geographical position. To a young nation, occupying an immense tract of country, and of course, without the amount of accumulations necessary to connect places both distant and comparatively unpopulous, the formation of the necessary roads or railways was next to hopeless. Nature had provided a way at once smoother than the most perfect railway, and having the power of immediately renewing the smoothness and perfection of its own surface, however deeply furrowed by the track of a moving body. It only remained for art to provide a vehicle and power capable of eliciting from those noble rivers the services to which they are adapted: American energy and enterprize have not been slow to turn those liquid highways into lines of the most astonishing and rapid intercourse which is to be found in the whole world. We frankly admit, that the river steamers of America stand in every respect in science, in beauty, in magnitude, in speed, unparalleled by the river steamers of our own or any other country. By a late return from the Secretary of the Treasury of the United

States, it appears that the whole number of steam boats ascertained and estimated to be in America in 1838, is from 700 to 800. " On the western and south-western waters alone, near 400 vessels are supposed to be running, where none were used till 1811; and where in 1834, the number was computed to be 234. On the Ohio river alone, in 1837, 413 different steam boats are reported to have passed through the Louisville and Portland Canal. As an illustration of the rapid increase of business in steam boats on the Ohio, the number of their passages throughout the Louisville Canal was, in 1831, 406 passages, and 1501 passages in 1837, being nearly fourfold in 6 years." The same document also contains the following avowal: It is a matter of surprise, that so few of these are sea-going vessels, considering that the first steam boat which ever crossed the Atlantic, was built in New York as long ago as 1819. The " Savannah went from Savannah to Liverpool in twenty-six days. The Robert Fulton, in 1822, made several trips to New Orleans and Havannah. The government of the United States never owned but two vessels of war—both called 'the Fulton,' the first was lost by accident, in 1829; and the second was built in 1838." It appears, therefore, that the people of America, and those of Great Britain, have each attained the superiority in those branches of steam navigation for which they possessed the greatest national facility, and to which they were urged by the strongest necessity.

The object of this short article on so important and extensive a subject, is necessarily limited. We design to give, *in the first place*, an account of the manner in which the practical art of steam navigation came to be introduced in Great Britain, and gradually matured and extended in America and at home. And, *in the second place*, to present an accurate representation, in outline, of the present condition of steam navigation. The difficulty of presenting an accurate history of steam navigation is great, owing chiefly to the doubts and disputes of contending parties for the honour of the invention. We have endeavoured to avoid these, by limiting our enquiries to the history of some of those efforts by which steam navigation was actually and immediately introduced into this country and into America, omitting or passing slightly over those many ingenious devices, which from time to time have served to demonstrate the ingenuity of individuals, or to illustrate the fertility of human invention, rather than to achieve any permanent influence on the welfare of mankind. In the latter part of the work, we have endeavoured to give an accurate view of the present state of steam navigation as the most improved practice has presented it to us, without entering into the multifarious practical details, which would not only have unfitted it for the general reader, but would also, from the transition state through which the art continues to march with rapid pace, be very soon rendered inapplicable by the continual introduction of novelty and improvement.

## CHAPTER I.

### *Invention of Steam Navigation.*

We regret that the limits and nature of this work do not permit us to enter largely into the detail of the interesting labours of all the ingenious men who have from time to time displayed great skill in combinations of mechanism, connected in various degrees of intimacy or remoteness with the subject of this notice. It is, however, quite necessary that we should limit our enquiries to the immediate discussion of this important historical question, Who are those men to whom society immediately owes the benefit of Navigation by Steam, that mighty power now carrying so rapidly forward the civilization and prosperity of the human race? To this alone we must confine our attention—who are the individuals without whose exertions we should have failed to be now enjoying the benefits we possess, and to whom the gratitude of ourselves and our posterity is to be heartily awarded? In this limited but more correct view of the subject, we shall no doubt be compelled to omit an interesting chapter of invention—the invention not of steam navigation itself, but of things concerning steam navigation. We shall have thus to omit the extended notices we might have introduced concerning the contrivances of the Ancient Egyptians, who used cattle moving round in a gin placed in a boat, to turn paddle wheels like those of the common steam boat, and so constructed ships propelled by four and six oxen power. Thus also we have to pass lightly over the interesting account which has been given of a similar employment of paddle boats by the Romans during the time of the Commonwealth to transport soldiers to Sicily, and an experiment of Prince Rupert, whose wheel boat beat the king's barge with sixteen oars, and Savary's Navigation Improved, in which it is proposed to propel vessels in calms by working the capstan connected with paddle wheels on the vessel's sides, as well as Bushnel's revolving oars, and the horse tow-vessel employed to take out ships from Chatham in adverse winds, as far back as 1682. Besides all of which, there are the galleys of Valturius and the Liburnæ mentioned by Pancirollus in his "History of many Memorable Things lost which were in use among the Antients," where he says, "I have seen representations of some ships called Liburnæ, which had three wheels on both sides without, touching the water, each consisting of eight boards jutting out from the wheels about an hand's-breadth, and turned by six oxen within, which by turning on a gin stirred the wheels, whose fellies driving the water backward, moved the Liburnæ with such a force, that no trireme galley was able to match them." And besides these, we might have derived some entertainment from examining the mechanism of the pastor of Berne, who piously regarded the works of nature as the fittest patterns of art, and has been proposed as a candidate for the honour of inventing the art of steam navigation, because at an early period he had proposed to suspend to either side of a ship two gigantic duck's feet to be propelled by a steam-engine, and by opening and shutting like huge umbrellas on each side of the hull to propel the vessel through the water—a project again revived by another candidate for the honour, the late indefatigable Stanhope. And to these we might have added the piston and rack of Papin; or, had time still further served, we might have followed, through its multifarious phases, the scheme for propelling by reaction, and first of these, the experiment of propulsion by firing a huge cannon backwards from the stern of the vessel, whereby it was ascertained that thirty barrels of gunpowder forwarded the boat ten miles in twenty-four hours; a plan improved by Dr Allan in his proposition to form a tunnel or pipe open at the stern, or hinder part of the vessel, and by means of a pump driven by a steam-engine to force water or air through it into the sea, so that by the reaction this would occasion the ship to be driven forward, "thereby imitating very accurately what the Author of Nature has shown us in the swimming of fishes, who proceed by protrusion with their tails,"—or indeed the thousand-and-one inventions of each and all of those, and similar schemes, produced and reproduced over and over again. But these and all such schemes, alternately ingenious or preposterous, plausible or absurd, we are compelled to pass over, and to bring our readers at once to the invention of steam navigation as it now exists.

It has been very usual to attribute the invention of the modern art of steam navigation to Patrick Miller, Esq. of Dalswinton, in Dumfries-shire, in Scotland. Two competitors have contested his claim. We shall soon see that to no one of the three can the palm be awarded. The creation of the steam-ship appears to have been an achievement too gigantic for any single man. It was produced by one of those happy combinations in which individuals are but tools working out each his part in a great system, of the whole of which no single one may have comprehended all the workings. The individuals who have contested the title of inventors of steam navigation, are PATRICK MILLER, JAMES TAYLOR, WILLIAM SYMINGTON.

After long and patient examination into the claims of these parties—after having gone over the papers, published and unpublished, of the parties advocating the claims of each candidate—after having examined all the individuals whose personal testimony to the facts of the case we have been able to obtain—after weighing the circumstances in which the evidence has been obtained and the testimony given, we have to present to our readers, as the result of the whole, this conclusion, that the art of steam navigation was the joint invention of these three, Patrick Miller, James Taylor, and William Symington; that to their efforts the world owes its present advantages.

The following history of this remarkable combination is that which, among much conflicting evidence, appears to contain such facts as are of undoubted authenticity:—

Mr Miller was a man much addicted to mechanical pursuits. He followed out such experiments as he conceived likely to advance the public welfare, with energy and without much regard to expense. That species of gun, now universally known as the carronade, was his invention, and the result of a long and expensive course of experiments in artillery. At the time when the history of steam navigation commences, he had been engaged in attempts to improve naval architecture. For this purpose he commenced by building ships of a much greater length proportionally to their breadth, than formerly in use. To render these long narrow vessels capable of carrying sail, they were to be united in pairs, to form what is called the twin-boat, and even in groups of three laid side by side, to form a triple boat, one of which he presented to the King of Sweden. Mr Miller was also engaged at the same time in a series of experiments on the efficiency of different methods of propelling vessels by other powers than the force of wind. For this purpose he conceived a wheel, now commonly called a paddle wheel, to be the most effective, having the arms of the wheel immersed in the water, and flat boards placed on the spokes, at right angles to the direction of motion; it was only necessary to apply the strength of men to the crank handle of the wheels, and turn them round in order to propel the vessel forward by means of the resistance of the water to the floats of the wheel. By this means Mr Miller proposed to propel vessels in calms, or off a lee shore.*

✓ In 1787 Mr Miller published an account of his naval experiments in a small volume which he printed at Edinburgh, in the French and English languages, and illustrated with plates and descriptions; and copies of it were presented to every sovereign in Europe, to the American States, and the Royal Societies of London and Edinburgh,

This work is the more interesting, on account of containing the first announcement of the great experiment on steam navigation. The following passages from the book itself will enable the reader to judge of Mr Miller's merit, and may perhaps serve to throw some light on the character of the man :—

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* We do not find that Mr Miller any where claims absolute property in the invention of paddle wheels. We find the ROMAN soldiers were conveyed to Sicily in wheel boats, driven by oxen.

It is also said that there exist some ancient paintings on EGYPTIAN tombs which represent paddle boats propelled by oxen.

With the use of wheel boats for purposes of war, it appears that the CHINESE have long been well acquainted. In the "Memoires concernant l'histoire, les sciences, les arts, &c. des Chinois," by the Jesuit missionaries at Pe-Kin, there is, at page 343, the following passage:—" Fig. 94, pourroit donner lieu à quelque invention utile pour faire avancer nos vaisseaux en tems de calme." On turning to the figure, we find the following very respectable war junk with two paddle wheels on each side, and this description —" Barque à roues"—forty-two feet long, thirteen feet wide. The wheels are in a recess, a foot wide, enclosed by strong planks; from the centre of the wheels there project oars, forming as it were teeth to the wheels, which project into the water to a foot in depth. The wheels are turned by men inside the boats.

"Inventions which have a tendency to promote the happiness or to increase the comforts of mankind in general, should, as soon as they have been brought to any kind of maturity, and can be described with tolerable precision, be communicated to the world at large. Impressed with this sentiment, I have caused to be engraved a plan and views of a triple vessel, constructed on a new principle, and also a plan and view of a wheel to give her motion through the water.

"The years I have applied myself to this subject, and the many experiments I have made with vessels which I caused to be built for the sole purpose of improving naval architecture, have given rise to the invention which I now communicate.

"The first and principal property of vessels constructed upon the plan here communicated, is derived from the wheels, the mechanism of which is simple and obvious. To work them, seamanship is not requisite ; for

Tigers' heads are represented on moveable pannels, covered with brass, five feet high, and two feet wide, for the purpose of covering the soldiers in the boat from the enemy; and they are removed when it is intended to leave the vessel."

Wheel boats seem to have been one of Mr Savary's favourite projects before he invented his steam-engine. Indeed, from the fifteenth to the end of the eighteenth century, they seem to have been taken up incessantly by one projector after another, as an excellent mode of propelling.

In this country, horses were used for turning round paddles, and propelling a boat, at the end of the seventeenth century; and it is not long since they were so used in America in common ferry-boats.

it can be performed even by the most ignorant, strength and agility in the men employed being all that is requisite. From the experiments I have made in different vessels with the wheels wrought by cranks, as shown in the plan, it appears to me that ships, however great their burden, if there be no wind, and the water is smooth, may be made to pass through it at the rate of from three to four miles an hour.

"When the movement of the wheel comes to be aided by mechanical powers so as to accelerate its revolution, the before-mentioned rate of a ship's going through the water, will be in proportion to the power used. I have also reason to believe THAT THE POWER OF THE STEAM-ENGINE MAY BE APPLIED TO WORK THE WHEELS SO AS TO GIVE THEM A QUICKER MOTION, and consequently to increase that of the ship. In the course of this summer I intend to make the experiment; and the result, if favourable, shall be communicated to the public."

The reader will thus be able to ascertain, how far Mr Miller's experiments had prepared a suitable vessel and mechanical apparatus for the reception, and successful application, of the steam-engine. But we should do injustice to the second member of the illustrious triumvirate, did we delay any longer to introduce to our readers Mr TAYLOR. We shall probably afford our readers a greater gratification by allowing Mr Taylor to introduce himself to them, "*propria persona*." In the autumn of 1785, (says Mr Taylor, in a narrative drawn up by himself, the authenticity and genuineness of which appears to us beyond a doubt,) "I went to live in Mr Miller's family as tutor to his two youngest sons. I found him a gentleman of great patriotism, generosity, and philanthropy, and at the same time, of a very speculative turn of mind. In the summer of 1786 I attended him repeatedly in his experiments (on paddle-wheel boats) at Leith, which I then viewed as parties of pleasure and amusement. But in the spring of 1787, a circumstance occurred which gave me a different opinion. Mr Miller had engaged in a sailing match with some gentlemen at Leith, against a customhouse boat, a wherry which was reckoned a first-rate sailer. A day was appointed, and I attended Mr Miller. His was a double vessel, sixty feet deck, propelled by two wheels, turned by two men each. We left the harbour in the forenoon, and sailed about for some hours in the frith; but the day falling calm, the customhouse boat could make little way. We landed on Inchcolm where we remained some hours waiting for a breeze to spring up. This accordingly happened in the afternoon—a very fine breeze from the west, and fair for the harbour of Leith. The customhouse boat was managed by a Mr Weddel; Mr Miller managed his own, manned by four men at the wheels, and we started at the same time for a fair run to the harbour. Our vessel beat by a few minutes. Being then young and stout, I took my share of the labour of the wheels, which I found very severe exercise; but it satisfied me that a proper power only was wanting to produce much utility from the invention. I was now led to converse with Mr Miller more frequently on the subject than formerly; and I observed to him, that unless he could apply to them a more commanding power than that of men, I was afraid the invention would be of little use. He answered, 'I am of the same opinion, and that power is just what I am in search of. I will explain my views—my object is to add mechanical aid to the natural force of the wind; to enable vessels to avoid or extricate themselves from dangerous situations, when they cannot do it on their present construction; and I wish also to give them powers of motion in time of calm. I am satisfied a capstan well manned can effect this purpose in part; but I want a power more extensively useful, which I have not as yet been able to attain. Now that you understand the subject, will you lend me the aid of your head, and see if you can suggest any plan to accomplish my purpose?' It became the daily subject of our conversation at leisure hours; we talked of many plans, but none of them satisfactory, or preferable to the capstan. At last, after beating over the whole system of mechanics, I said, 'Mr Miller, *I can suggest no power equal to the steam-engine, or so applicable to your purpose.*' He expressed some surprise, and said, 'That is a powerful agent, I admit, but will not answer my purpose; for when I wish chiefly to give aid, it cannot be used. In cases such as that disastrous event which happened lately, the wreck of a whole fleet on a lee shore on the coast of Spain, every fire on board must be extinguished, and of course such an engine would be of no use.' We continued our conversations, and very frequently reverted to the steam-engine. In the mean time, every wreck recorded in the newspapers called forth the philanthropic feelings of Mr Miller, and excited a strong desire to accomplish his purpose of preventing the waste of human life and property. The more I thought of the business, the more I became satisfied of the propriety of applying the steam-engine; and in various conversations, urged it as at least worthy of attention for inland navigation, rivers, canals, &c., if not for the purposes of general navigation.

" Mr Miller at last said, 'Mr Taylor, you are right.

If we cannot accomplish the whole, we may a part; but will you show me how you will connect the engine with my wheels, and I will think of it.' "

This conversation took place at Dalswinton in the summer of 1787, and it was subsequent to this conversation that Mr Miller wrote his treatise on ships, in which he first suggested the application of the power of steam to propelling ships by paddle wheels, a suggestion which resulted from this conversation.

In an agricultural county of Scotland, remote from the mechanical skill and industry of the capital, it was not possible to proceed further in the prosecution of their project than to strengthen each other's good resolutions by frequent and earnest intercommunication. The approach of winter brought with it the usual return of the Dalswinton party to the metropolis. It now became possible to take active measures for carrying their schemes into operation, and it was now for the first time that Mr Miller was introduced to the sagacious and accomplished mechanic, who will henceforth occupy a prominent place in this history, as the last member of our illustrious triad—the inventors of steam navigation.

William Symington was the schoolfellow and early companion of James Taylor. They were natives of Leadhills, and were both educated at Closeburn school, in Dumfries-shire, with the view of being sent to the University; and it seems probable that they were not only fellow-students at the same college, but that they occupied the same rooms. Symington had originally been designed for the Scottish church, but was led into a different profession by his love of mechanics, and he became a mining engineer. For the early appreciation of his merit he was indebted to Gilbert Meason, Esq. of Wanlockhead Lead Mines, and he appears to have enjoyed through life the benefit of that gentleman's friendship and assistance. Mr Symington had at an early period directed his attention to the improvement of the steam-engine; and his principal aim seems to have been, the construction of a compact and portable steam-engine adapted to the production of a continuous revolving motion. In this attempt he was perfectly successful—so much so indeed that he proposed applying his engine immediately to that object, and had actually constructed a working model of his steam carriage, at the very moment when the two projectors at Dalswinton were considering the feasibility of applying the same power to the paddle wheels of a ship. Thus almost simultaneously were projected the first terrestrial locomotive engine, and the first aquatic steam-engine.

It was during those conversations in which we left the two projectors so deeply engaged at Dalswinton, that Mr Taylor bethought himself of calling in to their assistance the mechanical skill and ingenuity of his old friend, Symington. Symington was then employed in his professional occupations at Wanlockhead Mines, and Taylor seems to have written him a full account of the plans they were concocting at Dalswinton, for there is in Mr Taylor's possession the following note from Symington to Taylor, bearing date August 20, 1787:—" I must make some remarks upon your summer's inventions, which, if once made to perform what their author gives them out for, will undoubtedly be one of the greatest wonders hitherto presented to the world, besides its being of considerable emolument to the projector. Great success to you, although overturning my schemes." No steps were, however, taken in the prosecution of the scheme until the return of Messrs Miller and Taylor to Edinburgh, in December, when they proposed to inspect the machinery of Mr Symington's model steam carriage, for the purpose of considering its applicability to their purpose of turning round their paddle wheels. Mr Miller and Mr Taylor accordingly met Mr Symington in Edinburgh, immediately on their return; at the house of Mr Meason, where the model of the locomotive engine was then deposited, and conversed with Mr Symington on the practicability of adapting a similar engine to that which turned his carriage wheels, to the purpose of turning the paddle wheels of Mr Miller's boat. In this very simple transposition of paddle wheels in the place of carriage wheels, Mr Symington appears to have seen no difficulty, nor was it likely that he should do so, for his locomotive engine appears, on examination of its plan, to have required but little change to adapt it to this application, and Mr Symington seems at once to have expressed his confidence in the applicability of his portable steam-engine to the paddle wheels of Mr Miller's boat as proposed by Mr Taylor, and to have undertaken the necessary adaptations.

The boiler of this engine was compact, and contained the fire wholly within it, and as the cylinders of the engine were already applied to turn round a wheel with a continuous motion, the most ordinary mechanical arrangement was enough for the application of it to the paddle wheel. The resolution to do so was at once adopted; an engine on Mr Symington's plan was constructed under his superintendence, and that of Mr

Taylor; the cylinders and other castings were made by George Watt, a founder at the back of Shakspeare Square, in Edinburgh, in the summer of 1788, and were sent off to Dalswinton, where they were put together by the two young men, and in October the task was accomplished; the engine, in a strong oak frame, was placed in the pleasure boat, the boiler being parallel to it on the opposite side of the vessel, and the paddles in the centre of the boat. The machine was first put in motion on the lake at Dalswinton, in the middle of October 1788, and a " more complete, successful, and beautiful experiment, was never made by any man at any time, either in art or science. The vessel moved delightfully, and notwithstanding the smallness of the cylinders, (four inches in diameter,) went at the rate of five miles an hour." Here the vessel continued to ply for some days for the amusement of the projector, and to the astonishment of the country people, who assembled from all quarters to witness the wonders of " a boat driven by reik," (smoke.) After having satisfied its projectors, the engine was removed into the library of Dalswinton house, where it stood for a long time as an ornamental model.

Thus, therefore, was completed, in the year 1788, a perfectly satisfactory trial of that great modern invention —the system of propelling vessels by means of paddle wheels driven by a steam-engine. We believe that there has never since that time been constructed a model steam vessel on the same scale, that has attained a greater velocity. The combination of men was admirable; the patriotic and wealthy experimentalist, the sagacious projector, the ingenious and experienced mechanic—Miller, Taylor, Symington. This happy union produced the modern steam-ship. The man who knows how extremely difficult a problem it is at the present day, with all our own experience and knowledge added to that of those gone before us, to produce a good steam ship; who knows how many are the points in which fatal errors may be committed, and failures result, will be able to appreciate the full measure of merit which comes to those men, who, at that early period, in the infancy of constructive machinery, produced a steam-vessel which, on so small a scale, attained the velocity of five miles an hour. A full account of the experiment was published in the newspapers of the day.

We shall by and by see that it is to this experiment, directly and immediately, that society owes all the blessings it derives from an art which has now attained a wonderful degree of perfection and a boundless sphere of usefulness. It is from this experiment that all the others to which society has been wont to look back with gratitude, have been primarily and immediately derived; and it is to these men that the everlasting gratitude of all nations, and most of all of the Ocean Queen, is to be in all truth and sincerity for ever rendered. Since that day, many others have done much to carry forward the invention, to perfect its details, and to extend its usefulness. To them be their meed of praise in due time cheerfully given. Theirs, too, was merit, this the brightest. But these labours are not yet ended.

Satisfactory as was the result of this first experiment, it did not fulfil all the patriotic purposes of the three. A model ship even so large as this, might succeed and still leave it doubtful whether a larger scale might not impair the efficiency of the contrivance. It is indeed, only too often the dire experience of the enthusiastic inventor, that his pretty little model conceals those defects which on a larger scale become fatal to his device. Mr Miller was well enough versed in experiments to know this, and determined to put the new system to the test of an expensive trial on the large scale. From this determination, resulted *the second steam boat.*

We have seen, that the *first steam boat* was constructed at Dalswinton, in 1788. The *second steam boat* was constructed by the same three at Carron, in 1789.

Before it was fairly agreed to undertake the new experiment, the winter season of (1788) was too near to admit of much being accomplished, and further progress was postponed until the following summer. It was proposed to make the second experiment on the Forth and Clyde Canal. For this purpose, Mr Miller's large pleasure boat which we have already mentioned, as having been propelled by paddle wheels driven by men, in the race in which the sailing vessel was beaten by it, this very boat, also a twin boat was sent up from Leith to the Forth and Clyde Canal at Grangemouth, on the Frith of Forth, to receive the new steam engine to be provided for it—this large vessel being 60 feet long, was to be propelled by engines of much greater power, and cylinders of 18 inches diameter were proposed for the engines. It may be imagined by some one, that defects had been discovered in the mechanism of the first steam boat, so as to render a second experiment necessary in which these deficiencies might be supplied, and former errors corrected. It is very important to prove that this was in no respect true—the details of the steam-engine, and of its connexion with the wheels and the construction of the boiler from which the modern marine boiler carrying the fire within it wholly surrounded by water—all these required no change whatever—the second steam boat was in all respects a larger machine than the first, but identical in construction, being an engine of about *twelve horse power*—whereas the first had been only about one horse power. So soon as the winter session had passed away, and Mr Taylor's duties as college tutor to the sons of Mr Miller being finished for the season, allowed him to leave Edinburgh, he was dispatched along with Mr Symington to Carron Iron Works, at that time the most celebrated foundery and workshop in Scotland, to begin the new undertaking. The date of commencing the second steam boat is fixed by the following letter, of which the original is in the possession of Mr Miller's eldest son.

" *Dunfermline*, *6th June* 1789.

" GENTLEMEN,

" The bearer Mr William Symington is employed by me to erect a steam-engine for a double vessel; which he proposes to have made at Carron. I have therefore to beg that you will order the engine to be made according to his directions. As it is of importance that the experiment should be made soon, I beg also that you will assist him, by your orders to the proper workmen, in having it done expeditiously. I am ever, with great regard, gentlemen, your most obedient humble servant,

" PATRICK MILLER.

" To the Carron Company, Carron."

The engine was accordingly set about immediately, and within six months was fitted up on board the vessel at lock No. 16. on the Forth and Clyde Canal, where there is a level reach about four miles long. The first trial was made in the presence of Mr Adam of Blair Adam, Mr Balfour of Pilrig, Mr Ambrose Tibbets, Mr Stainton, and a multitude of spectators. It turned out, however, that the boards of the paddle wheels were insufficient for the concussions to which the great power of the engine subjected them, and being broken off, rendered the experiment incomplete. They were, however, repaired, and on the 26th day of December 1789, the experiment was repeated, and *the vessel was propelled with perfect success at the rate of nearly seven miles an hour, being about as great a velocity as it has been found possible to obtain by steam boats on canals, even at the present day.* Next day the vessel repeated her voyage with the same success, having performed her trips so satisfactorily, that nothing further remained to be done. After this signal success nothing further remained to be accomplished in the way of experiment; the vessel being a slight skiff, with plank of less than an inch thick, and incapable of permanent use in this way, as soon as the experiments were over, was replaced in her original station as a pleasure boat at Bo'ness haven, the property of Mr Miller, and the engine deposited at Carron Works. An account of this experiment, drawn up by Lord Cullen, was afterwards published in the *Caledonian Mercury*, *Courant*, and *Advertiser*, Edinburgh newspapers—it is as follows :—

" It is with great pleasure I inform you, that the experiment which, some time ago, was made upon the

Great Canal here by Mr Miller of Dalswinton, for ascertaining the powers of the steam-engine when applied to sailing, has lately been repeated with great success. Although these experiments have been conducted under a variety of disadvantages, as having been made with a vessel built formerly for a different purpose, yet the velocity acquired was no less than from six and a half to seven miles an hour.

" This sufficiently shows, that with vessels properly constructed, a velocity of eight or nine, or even ten miles an hour, may be easily accomplished, and the advantages of so great a velocity in rivers, straits, &c., and in cases of emergency, will be sufficiently evident, as there can be few winds, tides, or currents which can easily impede or resist it, and it will be evident, that even with slower motion, the utmost advantage must result to inland navigation."

We have now brought the invention of steam navigation to a successful consummation in the hands of Miller, Symington, and Taylor. It only remains to show how the successful experiment was matured into a practical art—how the high velocity thus early attained was afterwards rendered the vehicle of benefit to mankind by forming an element in the intercourse of civilized communities.

If we consider the slow progress by which arts generally have attained the rank of social importance to which they have been destined to arrive, it will appear not a little marvellous, perhaps, that sixty years from this first experiment should have been enough to raise steam navigation to its present importance. Yet it has been asked, on the other hand; " if these experiments were at that time so perfectly successful, why did not these three, the inventors of the art, at once introduce it into practical use, as the means of inland transport, and derive from it the mercantile benefit due to the inventors of a new mode of commercial intercourse?" That man who is experimentally acquainted with the difficulties, anxiety, and disappointment, which in past times have generally attended the introduction of any new invention, will readily see that there remains very little to be accounted for in the circumstance that these gentlemen did not throw themselves into the sea of troubles which now presented itself to them if they should cease to be contented with having shown the world the means of doing that which the wants of society should one day require. Why should Mr Miller, a patriot, it is true, but a man now advanced in life, retired from business to the *otium cum dignitate* of his country seat, to the pursuit of agricultural recreations, and the education of his family, why should he spontaneously plunge into a war with the prejudices of the world, and the encumbrances of involved speculation? And Mr Taylor—what could the poor family tutor do to accomplish that which his master, who had the wealth, had not the hardihood to encounter? And Mr Symington, whose profession it was to apply the steam-engine, who was poor and isolated, and without the assistance of enlightened enterprise and large capital, what could he do more to produce a revolution so gigantic? Mr Miller felt that he had done all that his duty to mankind required when he put them in possession, by publication, of what he had done. Finding also, that in the experiments he had already made on various subjects for the public welfare, he had expended above L.30,000, which other men might have thought it their duty to bequeath to their family; and having, in his last steamboat, been brought into expenses much greater than he had ever anticipated; he felt it to be his duty, after having advertised the public of the success of his attempts, to leave that public fully at liberty to avail itself of all that had already been accomplished whenever it should think proper to do so.

## CHAPTER II.

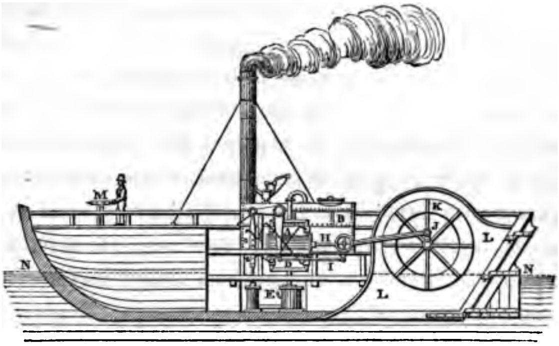
### *On the Practical Introduction of Steam Navigation into Mercantile Use.*

FROM the invention of the modern steam boat, by Miller, Symington, and Taylor, we now pass on to trace the steps by which steam navigation was introduced as the vehicle of commercial intercourse, and gradually became matured into an important practical art.

We shall see, that the beautiful and successful experiments of Dalswinton already recited, form the source from which directly, and without any intermixture whatever, the civilized nations of the world have derived the blessings of steam navigation. We have seen, that in the hands of those three men all difficulties had disappeared, and that with a very moderate size of boat and engine, a velocity of 6 to 7 miles an hour had been practically obtained so early as the year 1789.

After these experiments had been brought to a successful termination, it became necessary for Mr SYMINGTON to return to the fulfilment of his ordinary duties, as engineer of the Wanlockhead Mining Company. These duties he continued assiduously to perform for a period of ten years, when he was once more diverted from the field of private industry into that of public enterprize, by an intelligent and spirited nobleman, the late Thomas LORD DUNDAS of Kerse, an extensive proprietor in the Forth and Clyde Canal. His lordship was desirous to avail himself of this new locomotive power, for the purpose of forwarding the interests of the proprietors of that excellent system of inland navigation; and applied to Mr Symington to construct a steam-vessel for the purpose of superseding the use of horses in towing vessels along the canal. A steam-vessel was accordingly built by Mr Symington, and completed in 1802. The following is Mr Symington's narrative of the experiment, which we have seen confirmed in all particulars by the testimony of an eye-witness. "Having previously made various experiments, in March 1802, at Lock No. 20, Lord Dundas, the great patron and steam boat promoter, along with Archibald Speirs, Esq. of Elderslee, and several gentlemen of their acquaintance, being on board, the steam boat took in drag two loaded vessels, Active and Euphemia of Grangemouth, Gow and Elspine, masters, each upwards of 70 tons burden, and with great ease carried them through the long reach of the Forth and Clyde Canal, to Port Dundas, a distance of 19½ miles, in six hours, although the whole time it blew a very strong breeze right a-head of us; so much so, that no other vessels could move to windward in the canal that day, but those we had in tow."

The performance of this steam tug appears to be about as great as any since accomplished by the many boats which on the same canal have attempted the same duty. A foolish prejudice, that the action of the paddle wheels would injure the banks of the canal, seems then to have preoccupied the minds of the directors, and the plan was not adopted. We have here given an authentic drawing of this boat, and it is curious to observe the peculiarities of the paddle wheel at the stern, and of the steering apparatus in front, both claimed as inventions of a later date. The cylinder of the steam-engine was of 22 inches diameter, with a stroke of four feet; placed with its axis horizontal, and turning the wheel with a crank. When unimpeded by having other boats to draw after it, this vessel went steadily at the rate of six miles an hour.



We have now reached that point of our history, where the glory of having introduced steam navigation to the attention of the world, leaves its inventors, to irradiate the names of others who reaped the benefit of their labours. Of those men who have occupied the largest space in the world's eye in connexion with the history of steam navigation, there stands out first and most prominent, the name of Fulton.

Robert Fulton, an Irishman by blood, and an American by birth, was born in 1765, in Little Britain, in the

State of Pennsylvania. His parents were humble and poor, and gave their son no more than the ordinary rudiments of English education at a country school; but his taste for mechanics and drawing developed itself in early life, and at the age of seventeen the self-taught artist was able to earn a livelihood by his pencil. At the age of twenty-one he had acquired the acquaintance of Franklin, and had accumulated a sufficient sum from the savings of his industry to purchase a farm for his mother, and undertake, in 1786, a journey to England, for the purpose at once of cultivating his art and pushing his fortune. In both of these he appears to have been tolerably successful.

Some years after this, Mr Fulton appears to have been directing his attention to mechanical projects, for in 1794 we find him taking out a patent for improvements in canals, and especially for a double-inclined plane forming a substitute for locks in the translation of vessels to different levels on a canal. He now began to assume the title of *civil engineer*, under which title he brought out a treatise on Canal Navigation.

About the year 1797, Mr Fulton migrated to Paris, where he resided for the seven following years in the house of his countryman, Joel Barlow. Here he endeavoured, by assiduous study, to supply the deficiencies of his early education, and became the inventor and proprietor of panoramic exhibitions. But the principal subject that occupied his attention during this period of time, seems to have been a project of submarine warfare, submarine locomotion, and submarine explosions. To this subject he appears to have devoted himself with all the energy, and we may say with all the infatuation, of a most sanguine schemer. In 1801 we find him at the harbour of Brest making experiments with his submarine boat, which he called the Nautilus, attempting to blow up the English ships then blockading the coast of France, with his submarine bombs or torpedoes. The only result of his labours, however, was this, that on one occasion he got very near an English seventy-four, which moved out of the way just before he had time to blow her up.

Disappointed in France, Mr Fulton opened a negotiation with the British Government, to apply himself with equal ingenuity to the invention of machinery calculated to blow up his former allies the French; but in this attempt he was equally unsuccessful.

Mr Fulton was obviously one of those men who delight in the exciting occupation of following out new schemes and projects, and it is not a little curious that he should have arrived in England just before the date of the trial of the Dalswinton and the Carron steam boats, so that his attention must have been very naturally attracted to so interesting a mechanical subject: that his attention was so directed, is shown from sketches and memoranda on the subject, found among his papers. We also find him writing to Scotland to obtain information regarding Mr Miller's vessels. But it does not appear that the subject was seriously entertained by Mr Fulton until an ulterior period, at which we shall now resume the thread of our history of steam navigation.

While Mr Fulton was in Paris, he appears to have entered into conversation with CHANCELLOR LIVINGSTONE at that time (1801) the representative of America at the court of France, concerning the importance of the new application of steam power to the navigation of the lakes and rivers of their own country. It should be premised that Livingstone had himself been engaged about nine years after Miller's successful experiments, in an attempt to introduce steam navigation in America, in which he was conjoined with a person of the name of Nisbet, and assisted by the mechanical talent of Mark I. Brunel, the engineer, whose ingenuity has gained him so much reputation in other departments of mechanical combination; but the attempt had entirely failed, and did not produce a speed of three miles an hour, and the project was abandoned. Mr Livingstone, however, spoke to Mr Fulton of his intention to resume the subject on his return to America, and desired him to co-operate with him in the enterprise, and to direct his talent for mechanical combination towards that object. Mr Fulton at once agreed to devote to the subject as much time as he could spare from his favourite schemes of submarine explosion.

We have great pleasure in bearing testimony to the judgment with which Mr Fulton proceeded in commencing his career in steam navigation. Mrs Barlow, the lady of his friend already noticed, was ordered to Plombieres by her physicians, in the spring of 1802, and was accompanied by Mr Fulton, who forthwith employed his leisure in experiments on models, for which the small stream that runs through that village afforded adequate facilities. He appears to have been satisfied that endless chains with floats attached to them, made to revolve by wheels on the surface of the water, were the best apparatus, and therefore preferable to Mr Miller's paddle wheels.

But Mr Fulton found that he had been anticipated in this idea by a Frenchman, named Des Blancs, who had taken a patent for propelling boats by what he called chaplets, which were exactly Fulton's endless chains, and had also made experiments with them at great expense, without commensurate success. Mr Fulton was thus thrown back upon Mr Miller's original plan of propelling by the steam-engine acting on paddle wheels. He accordingly, in the winter of 1802–3, made a small model, and wrote a description of a small steam boat with paddle wheels.

About the same time, Mr Livingstone and Mr Fulton commenced the construction of an experimental steamboat on a larger scale. It was launched in the spring of 1803, on the Seine, below Paris, and the steam-engine and boilers were put on board. Mr Fulton had, however, made the same mistake which many steam boat builders have done at a much later date—he miscalculated the strength of his vessel, and when the weight of the machinery was placed in the centre, she broke through the middle and went to the bottom.

The shattered vessel was raised, and was found to be almost entirely broken up. How admirable are the lessons inculcated by a thorough failure! The American steam boats have ever since been distinguished by the excellence of the strong and light framing by which their slender vessels are enabled to bear the weight and strain of their large and powerful engines.

This disaster compelled Mr Fulton to devise the means of so strengthening a vessel, as to carry with safety her engines and machinery. He was obliged to set about building an almost entirely new vessel to carry his machinery, which suffered very little from the submersion, and at length, in August 1803, Mr Fulton made an experiment on his vessel. The vessel was sixty-six feet long and eight feet wide; but she moved so slowly as to be altogether a failure.

It was soon after this experiment with the steam vessel, that Mr Fulton came over to Britain for the purpose of engaging in the torpedo warfare, and turning those dreadful submarine engines against his allies in France. It will be readily conceived, that after having encountered so many difficulties in his own attempt at steam navigation, he would not allow any opportunity to escape, of obtaining information regarding the progress which had been made in Scotland since his departure; especially as the performance of his experimental vessel, notwithstanding his having employed Mr Miller's plan of propelling by wheels, had fallen so far short of the performance of both the first and second vessels constructed by Miller, Symington, and Taylor. Now, our readers will recollect that before the date of Mr Fulton's return to Britain, 1803, Mr Symington had constructed a third steam-vessel, with which, even on the canal, he obtained the velocity of six miles an hour. We may also add that the fame of Mr Symington's experiments had by this time attracted much attention throughout Great Britain, and he had already received an order from the Duke of Bridgewater to construct steam vessels on his plan for his canal. We accordingly find that Mr Fulton availed himself of his residence in Britain, to pay a visit to the scene of these successful experiments. It is clearly established that while Mr Symington was carrying on his experiments under Lord Dundas with his third steam vessel, and endeavouring to introduce steam as the towing power on canals, the following occurrence took place :—

Mr Fulton called upon Mr Symington, and introducing himself, told him that being about to return to America, he had heard of the steam boat experiments, and could not leave Great Britain without first waiting on Mr Symington, in the hope of being allowed to see the boat, and to obtain such information about it as he (Mr Symington) might be willing to communicate. Mr Fulton then mentioned, that, however advantageous steam navigation might prove to Great Britain, it would certainly become much more so in America, on account of the many extensive navigable rivers in that country, and as timber of the best quality, both for building the vessel and affording fuel to the engine, could be purchased there at small expense, Mr Fulton expressed his opinion that it could hardly fail to become beneficial to trade in that part of the world. Mr Symington accordingly gave him all the information he desired, and put himself to considerable trouble for the purpose of affording him the best opportunity of satisfying himself of the complete success of steam navigation at that time in Scotland. Our readers will not, we hope, be displeased to have an account of the trip from Mr Symington himself, an account corroborated by the evidence of respectable witnesses.

Mr Symington, after giving an account of Mr Fulton's introducing himself, and of a conversation between them, in which the latter proposed that they should participate in the advantages to be derived "from carrying the plan into North America," continues, "Mr Fulton having thus spoken, in compliance with his most earnest request, I caused the engine fire to be lighted up, and in a short time thereafter put the steam boat in motion, and carried him from Lock No. 16, where the boat then lay, four miles west the canal, and returned to the place of starting, in one hour and twenty minutes, to the great astonishment of Mr Fulton and several gentlemen who at our outset chanced to come on board.

"During the above trip Mr Fulton asked if I had any objections to his taking notes respecting the steam boat, to which question I said—none; as I considered the more publicity that was given to any discovery intended for general good, so much the better; and having the privilege secured by letters-patent, I was not afraid of his making any encroachment upon my right in the British dominions, though in the United States, I was well aware I had no power of control. In consequence, he pulled out a memorandum-book, and after putting several pointed questions respecting the general construction and effect of the machine, which I answered in a most explicit manner, he jotted down particularly every thing then described, with his own remarks upon the boat, while moving with him on board along the canal; but he seems to have been altogether forgetful of this, as, notwithstanding his fair promises, I never heard any thing more of him till reading in a newspaper an account of his death."

We may readily judge of Mr Fulton's astonishment when he saw *that* successfully accomplished in a remote corner of Scotland by a plain unpretending man, to which he had applied so much study and talent in vain. He had been propelled in a boat driven by paddles in a narrow and difficult canal, at a rate of more than six miles an hour, whereas in his own vessel he had not got a speed of three. He was not slow to avail himself of his newly acquired knowledge. He waited on the younger Mr Watt, of Bolton and Watt, at their establishment near Birmingham, and, under a feigned name, made proposals to them to assist him by the construction of a steam-engine suited to the purpose of propelling a steam vessel. The disguise of Fulton, for whatever purpose assumed, was soon found out; Mr Watt did not, however, allow this "indirection" to interfere with the fulfilment of his bargain, and an engine to be calculated for the propulsion of a vessel at the desired speed, was accordingly put in hands for Messrs Livingstone and Fulton.

Fulton having met with as little success in his plans of blowing up French frigates with English gunpowder, as he had formerly obtained in his attempts to blow up British frigates with French gunpowder, did not remain long in England. He returned with his friend Mr Livingstone to America, where the marine engine of Messrs Bolton and Watt was about to follow them. In the mean time, the success of Mr Symington's boat had given them confidence and instruction, and Mr Livingstone had written to America, and secured the monopoly of steam navigation to Fulton and himself in the State of New York, for *their invention* of steam boats.

It was in 1806 that Bolton and Watt's marine engine reached America. It was used to propel the boat on Mr Miller's plan, by the use of paddle wheels. The shell of the vessel was launched in the spring of 1807, from the building yard of Charles Brown, on the East (Hudson) River. She was named the Clermont, (the name of Livingstone's residence) and attained a speed of nearly *five* miles an hour. It is worthy of remark, in justice to the inventors of steam navigation, that the first vessel of Miller, Symington, and Taylor had a velocity of more than *five* miles an hour in 1788, and their second, in 1789, went at a rate of nearly *seven* miles an hour, while Mr

Fulton, their imitator and follower, had himself been taken at a speed of above *six* miles an hour by Symington, in a narrow canal, several years prior to this date. The reader will easily understand that this performance on the part of the Clermont, even with the advantage of Mr Watt's excellent engine, was such as to fall far short of Mr Fulton's expectations. Such is the history of the introduction of steam navigation in America, in imitation of what had already been accomplished in Scotland.

Although the invention of steam navigation was thus perfected in Scotland, and thence transplanted directly by Fulton to America, the mercantile success of the young art was much more immediate and rapid in the new soil than in the old country. In the old country overgrown with old habits and prejudices, the young plant was overtopped and choked up, so that its progress was slow and difficult, while in the new and unoccupied field of America, watered by her mighty navigable rivers, it was early fostered and brought to maturity, so as to supply at once a new medium of communication expressly suited to the singular position and character of that young country.

It may not be uninteresting, and must certainly be instructive to follow, for a short time, the young art of steam navigation, transplanted from Scotland to the new world, in its rapid progress towards maturity. We have seen Mr Fulton's first boat, the Clermont, launched and set in motion in the spring of 1807. The following account of the first experiments is given with much *naïveté* by the American biographer of Fulton:—" Mr Livingstone and Mr Fulton had invited many of their friends to witness the first trial. Nothing could exceed," says he, "the surprise and admiration of all who witnessed the experiment. The minds of the most incredulous were changed in a few minutes. Before the boat had made the progress of a quarter of a mile, the greatest unbeliever must have been converted. The man who while he looked on the expensive machine, thanked his stars that he had more wisdom than to waste his money on such idle schemes, changed the expression of his features as the boat moved from the wharf, and gained her speed—his complacent smile gradually stiffened into an expression of wonder. The jeers of the ignorant, who had neither sense nor feeling enough to suppress their contemptuous ridicule and rude jokes, were silenced for a moment by a vulgar astonishment which deprived them of the power of utterance, till the triumph of genius extorted from the incredulous multitude which crowded the shores, shouts and acclamations of congratulation and applause." The boat had not been long under way when Fulton ordered her engine to be stopped. The paddle floats were too deeply immersed in the water, and he had them brought nearer to the centre, so as to lessen the diameter of the wheel, and take less hold of the water; and when they were again put in motion, it was manifest that the alteration had increased the speed of the boat.

Some time after this first experiment, it was announced in the newspapers of the day, that the Clermont steam boat, built by Messrs Livingtone and Fulton, with a view to the navigation of the Mississippi river from New Orleans upwards, would depart from New York for Albany, in the afternoon; Mr Fulton was himself a passenger on this voyage, and upon his return published an account of it as follows:

" *To the Editor of the American Citizen.*

" SIR,—I arrived this afternoon at four o'clock in the steam boat from Albany. As the success of my experiment gives me great hopes that such boats may be rendered of great importance to my country, to prevent erroneous opinions, and give some satisfaction to the friends of useful improvements, you will have the goodness to publish the following statement of facts :—

" I left New York on Monday at one o'clock, and arrived at Clermont, the seat of Chancellor Livingstone, at one o'clock on Tuesday—time twenty-four hours, distance 110 miles. On Wednesday I left the Chancellor's at nine in the morning, and arrived at Albany at five in the afternoon—distance forty miles; time eight hours. The run is 150 miles in thirty-two hours, equal to nearly five miles an hour, &c.

" ROBERT FULTON."

The Clermont performed the voyage back also without accident, at the same rate, being five miles an hour. And thereafter made several trips as a passage-boat during that season between New York and Albany; but met with many accidents, especially arising from the imperfections of her paddle wheels, which were of cast iron. The wheels also were hung without any support beyond the side of the vessel. And in addition to these difficulties the boat had to contend with the opposition of the traders and sailing vessels on the river, who were constantly endeavouring, by collision, to injure this new invader of vested rights. The vessel was laid up during the winter, and enlarged and strengthened; and in the spring of 1808 she again commenced plying as a passage-boat, and continued during the season. She was crowded with passengers.

In consequence of the success of this vessel, Messrs Livingstone and Fulton built, soon after, two other vessels, named the Car of Neptune and the Paragon, of 300 and 350 tons respectively.

Mr Fulton having risen to high estimation and extensive influence, died on the 24th day of February 1815.

Although we have seen that Fulton was not in any respect or degree entitled to the honour of inventing steam navigation, yet it is to him that America owes a debt of gratitude for having, in conjunction with Mr Livingstone, so early and so successfully transferred to America, all the benefits arising from the invention and successful application in this country, of the power of steam to the paddle wheel boat, by Miller, Symington, and Taylor, and by one of these gentlemen directly placed for that purpose in the hands of Mr Fulton. Although, therefore, America, in common with the rest of the world, will look to this country as the source from which she derived this benefit, yet we heartily join with her in paying honour to the memory of Fulton, as a man of no ordinary enterprise, energy, and perseverance, whose exertions not only conferred the advantages of steam navigation on the inland waters of America, at a very early period, but also materially contributed to the advancement of the great cause of steam navigation in that very country from which it had first emerged.

We now return to our own country, in which the cause of steam navigation lingered. We have seen that Miller, Symington, and Taylor had brought the art of steam navigation to such perfection, that it only remained for the mercantile speculator to take it up as a commercial enterprise. The speed of six to seven miles an hour, which they had obtained, was sufficient for the wants of commerce; and it must remain a subject of wonder that our countrymen were slow to avail themselves of this new machinery of translation, and had allowed two Americans to carry off the invention of their countrymen, and turn it to valuable account while the merchants of Britain slept. Thus much, perhaps, we may say for our countrymen, that their ample and varied means of transport rendered steam navigation less necessary to them than to the Americans, who possessed no highways but their magnificent inland navigation, those watery ways on whose smooth surface no load, however ponderous, leaves any permanent furrow.

Henry Bell of Helensburgh, on the river Clyde, was the first person in Great Britain who applied the invention of the Dalswinton trio to mercantile use—Bell occupies the same place with reference to Britain in which Livingstone and Fulton stood to America. Neither party had any share whatever in the invention; both were mere speculators, trying to turn the invention of others to profitable account. In one point, however, Bell has the advantage of Fulton; Fulton's first boat utterly failed. Bell's perfectly succeeded. The cause of this was plain: both were imitators of the Dalswinton mechanicians; but Bell being better acquainted with the details of the Dalswinton train of experiments, kept closer in his imitation to the original than Fulton, and was therefore more successful. Bell's first steam boat, the Comet, placed on the Clyde, was at least equally successful with Fulton's second boat, the Clermont, on the Hudson.

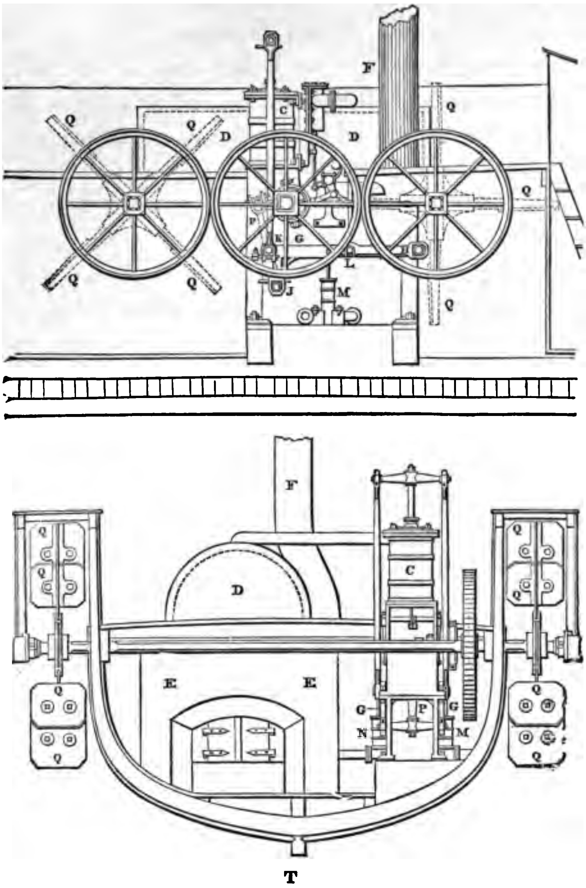
Mr Henry Bell was for many years a house carpenter in the city of Glasgow. He is described by those who knew him as a man of considerable shrewdness, possessing a rich vein of vulgar humour, and fond of what are called schemes; that is, of speculations sufficiently remote in their nature from common objects of enterprise, to confer upon the plausible projector notoriety, if not wealth. In the year 1808 he became proprietor of an establishment somewhat of this description. Helensburgh is a watering place on the river Clyde, opposite to Greenock, which used to furnish fashionable bathing quarters to the citizens of Glasgow; and in the months of June, July, and August, Helensburgh being crowded with visitors, it had occurred to a mind fertile in projects, that an establishment of the nature of hotel or bath-house, would prove a good speculation. Of such an establishment Henry Bell became proprietor in 1808.

It was for the purpose of increasing the facilities of reaching these baths that Mr Bell first constructed his steam-boats. There were in those days no conveyances on the river except certain fly-boats, being long jolly boat sort of things, capable of being pulled by four rowers, or of using sails when practicable. With these the voyage might sometimes be made in five to six hours; but oftener the time was longer and always uncertain. The labour of rowing, too, was very severe, and unwillingly resorted to when it could be at all dispensed with. Hence it was, that Bell was desirous to avail himself of the principle so frequently elaborated by modern projectors of railways and other new modes of transport, that every increased facility of communication increases in a very high proportion the number of those who travel. We accordingly find him contemplating a scheme of this sort soon after he had possession of the baths. He appears first of all to have attempted using paddles driven by hand, instead of oars, so as to propel the said passage or fly-boats between Glasgow and the baths at Helensburgh, more rapidly than formerly, and with less force. In this project he was foiled, as all men will be who attempt to propel a boat by human strength, through any other mechanism than the oar, which, when well proportioned and properly applied, is the best of all known methods of giving out usefully the whole of a man's strength. He tried many different arrangements of paddle wheels for this purpose equally without success. At last he became convinced that steam power alone would effect his object, and being previously well acquainted with the experiments of Miller, Symington, and Taylor, and having also access to visit Symington's third boat on the Canal, and knowing the success Fulton had met with in applying the British invention to profitable use in America, Bell determined to try this power on the Clyde, and produced, as is generally known, the first trading steam vessel in Europe in the year 1812, the Comet of Clyde.

The following is Mr Bell's own statement of the case, which was addressed by him to the Editor of the *Caledonian Mercury*, and published in that paper in October 1816:—" SIR, I observed in your paper lately a paragraph respecting steam boats, in which the Americans claimed the right to the discovery which is become of so much utility to the public. On this account I propose to give you a full statement of what I conceive to be the truth. Mr Miller of Dalswinton first wrote upon the method of moving or impelling vessels or rafts through water by paddles, wrought by a capstan, or by the wind, in the manner of a windmill, which idea he afterwards gave to all the different Courts in Europe. It will be recollected by most people in this country, that the French proposed to erect rafts for conveying troops to invade this country by means of Mr Miller's windmill or capstan plan; for it may be stated that this gentleman built two vessels at Leith, and put them in motion upon his new improvement, and even sent one of them to the King of Sweden, as a present. After this he thought that an engine could be so constructed as to be applied to work his machinery for the moving of his paddles; and accordingly he employed an engineer to put his plans in execution. But to give you a more correct account of the manner Mr Fulton, the American engineer, came to the knowledge of steam boats, that gentleman had occasion to write me about the plans of some machinery in this country, and begged the favour of me to call on Mr Miller of Dalswinton, and see how he had succeeded in his steam boat plan; and if it answered the end, I was to send him a full drawing and description of it, along with my machinery. This led me to have a conversation with the late Mr Miller, and he gave me every information I could wish for at the time; I told him where, in my opinion, he had erred, or was misled by his engineer; and, at the same time, I told him that I intended to give Mr Fulton my opinion on steam boats: the friends of Mr Miller must have amongst their papers Mr Fulton's letter to me, for I left it with Mr Miller. Two years thereafter I had a letter from Mr Fulton, letting me know that he had constructed a steam boat from the different drawings of machinery I had sent him out, which was likely to answer the end, but required some improvement on it. This letter I sent to Mr Miller, for his information, which must also be among his papers. This letter led me to think of the absurdity of writing my opinion to other countries, and not putting it in practice myself in my own country; and, from these considerations, I was roused to set on foot a steam boat, for which I made a number of different models, before I was satisfied. When I was convinced that they would answer the end, I contracted with Messrs John Wood and Company, ship-builders in Port-Glasgow, to build me a steam vessel, according to my plans, forty feet keel, and ten feet six inches beam, which I fitted up with an engine and paddles, and called her the *Comet*, because she was built and finished the same year that a comet appeared in the north-west part of Scotland. This vessel is the first steam boat built in Europe that answered the end, and is at this present time upon the best and simplest method of any of them; for a person sitting in the cabin will hardly hear the engine at work."

Mr Bell's Comet began to ply from Glasgow to Helensburgh in January 1812. She was capable of performing about five miles an hour. She continued during the whole summer to ply successfully as a passenger-boat, and, in consequence of her success, was soon followed by the long series of steam vessels for which the river Clyde has been so much distinguished.

The details of this first European trading steam vessel are next in interest, at least to a Briton, to the details of the first steam vessel of 1789, as already given. It was, therefore, with us a matter of curiosity to obtain its details for our readers. The original boiler of the Comet is now the author's property, and, having been favoured with a drawing of the engine and vessel, he is now enabled to present the reader with a faithful reproduction of her engines and machinery.



D the boiler, E E the brickwork in which it is set, F the chimney, C the cylinder, K P the connecting rod and crank rod, N M the pumps, J L H lever for working the pumps, &c., Q Q Q Q the paddles.

The Comet had obviously two paddle-wheels, or rather two sets of radiating paddles on each side. They are described as having resembled very much in their appearance four malt shovels, radiating from a revolving axis to which they were all fixed. This was soon changed, Mr Bell being compelled to resort to Mr Miller's complete wheel, which has been in use ever since. This engine was put up by workmen under Mr Bell's superintendence, The engine is of the kind known as the bell-crank engine, on Mr Watt's principle. The boiler was every way inferior to the boilers used in the previous three vessels of Miller, Taylor, and Symington, in as much as the fire was on the outside of the boiler, separated from the wood of the vessel only by the bricks in which it was set; while in their original boilers of 1789 and 1790, the fire was, exactly as in all steam vessels of the present day, wholly within the boiler, and perfectly surrounded by water, so as to prevent danger from accident by fire or loss of heat. It will also be noticed that the boiler was on one side of the engine, the funnel being bent so as to bring it to the centre where it served the purpose of a mast to carry sail. It seems indeed to have been the anxious wish of the constructors of the early steam boats to disguise the odious smoking funnel under the designation of a main-mast; and some even went so far as to raise up a top-mast in the thick folds of the dense black smoke. It is now, however, admitted that a steamer is a steamer having paddles and smoke, and not a ship entitled to white sails and a smooth side; and such is the force of habit, that even the picturesque is not awanting to the portrait of the diligent and faithful steamer toiling along its rapid path of active duty.

The Comet was a vessel of about twenty-five tons.

The engine of the Comet exerted a force of about three horse power.

The Comet was built by John Wood of Port Glasgow.

Mr Bell had employed in his experiments on fly-boats an engineer called John Thomson, of Glasgow. Thomson appears to have assisted Bell in planning his first boat, and to have felt himself ill treated by Bell in not being made a partner in that speculation. To avenge his wrong, he got Mr Wood to build a vessel fifty-one feet keel, twelve feet beam, and five feet deep. The keel was laid in March 1812, and in March 1813 the Elizabeth, the second steamer on the Clyde was started, and continued to ply successfully, eclipsing Henry Bell's Comet, and bringing much profit to her owner. This was probably the first *remunerating* steam vessel in the world. The tonnage of this vessel was about thirty-three tons, and her power about ten horses. This very correct proportion of power to tonnage seems to have been the secret of his success. The following description of this vessel by her owner, is an interesting and characteristic memorial of the early steam navigation. "The Elizabeth was started for passengers on the 9th of March 1813, and has continued to run from Glasgow to Greenock daily, leaving Glasgow in the morning, and returning the same evening. The passage, which is twenty-seven miles, has been made with a hundred passengers on board in something less than four hours, and in favourable circumstances, in two hours and three quarters. The Elizabeth has sailed eighty-one miles in one day, at an average of *nine miles an hour*.

"The Elizabeth measures aloft fifty-eight feet; the best cabin is twenty-one feet long, eleven feet three at midships, and nine feet four inches aft, seated all round, and covered with handsome carpeting. A sofa, clothed with marone, is placed at one end of the cabin, and gives the whole a warm and cheerful appearance. There are twelve small windows, each finished with marone curtains, with tassels, fringes, and velvet cornices, ornamented with gilt ornaments, having altogether a very rich effect. Above the sofa there is a large mirror suspended, and at each side book-shelves are placed, containing a collection of the best authors, for the amusement and edification of those who may avail themselves of them during the passage—other amusements are likewise to be had on board.

"The engine stands amidships, and requires a considerable space in length, and all the breadth of the vessel. The forecastle, which is rather small, is about eleven feet six, by nine feet six inches, not quite so comfortable as the after one, but well calculated for a cold day, and by no means disagreeable in a warm one: all the windows in both the cabins are made in such a way as to shift up and down like those of a coach, admitting a very free circulation of fresh air. From the height of the roofs of both cabins, which are about seven feet four inches, they will be extremely pleasant and healthful in the summer months for those who may favour the boat in parties of pleasure.

"Already the public advantages of this mode of conveyance have been generally acknowledged: indeed it may without exaggeration be said, that the intercourse, through the medium of the steam boats, between Glasgow and Greenock, has, comparatively speaking, brought these places ten or twelve miles nearer to each other. In most cases the passages are made in the same time as by the coaches; and they have been, in numerous instances, done with greater rapidity. In comparing the comfortableness of these conveyances, the preference will be given decidedly to the steam boat. Besides all this, a great saving, in point of expense, is produced; the fare in the best cabin being only four shillings, and in the inferior one two shillings and sixpence; whereas the inside of a coach costs not less than twelve shillings, and the outside eight shillings."

Such were the humble beginnings, not thirty years ago, of that art, which now embraces the entire globe in the meshes of its net-work of intercommunication. In the river Clyde itself, the progress of steam navigation is astonishing. Instead of the two little vessels of three and ten horse power, the waters of the Clyde are now navigated by frigates of 1400 to 2000 tons, propelled by engines exerting the power of five to six hundred horses. The little wonderful cabin, "eleven feet wide, with handsome carpeting, and its single sofa, clothed with marone, and the curtains with tassels, fringes, and velvet cornices," the wonder of the day, is now replaced by the noble saloon, eighty feet long, by thirty feet wide, profuse in all the luxuries of a noble mansion —the speed of seven miles is replaced by that of twelve to fifteen miles an hour; the ships which cover the Clyde exceed a hundred, and the vessels built on its banks are now to be met in almost every civilized portion of the ocean world. The city of Glasgow, brought so much nearer by the "low price of eight shillings to Greenock," is now at the distance of a single shilling, the passenger being taken now, in shorter time and greater comfort for one penny, the distance which formerly cost him a shilling; and the number of passengers annually availing themselves of such a conveyance, amounts to upwards of a million. What blessings, what advantages, what enjoyments, has this invention bestowed in so short a time on so great a number of our fellow men! How great are the blessings to society that still remain in the destiny of the human race to be derived from the introduction of ocean steam navigation!

## CHAPTER III.

### *Contending Claims to the Invention of Steam Navigation.*

It is not a little singular, that a nation which is the slowest to appreciate, and the most pitifully mean in rewarding inventive talent, should be notoriously clamorous about arrogating to itself as national property, the very honours which it has rewarded, if at all, with a tardy and niggardly hand. Such a nation is our own. It sets up a claim, (fortunately a just one,) and glories, as well it may, in being the fatherland of the steam-engine; and yet allows the son of Watt to pass through life unnoticed, unrewarded, unacknowledged; and, in like manner, it is most anxious to establish its claim, (fortunately also a just one,) to the invention of steam navigation, while the widows and orphans of the men who have given it that honour for which it so eagerly pleads its right, are allowed to plead in vain, or to lament in silence the paltry meanness of that nation which their parents made rich by expending the provision of their children. If it were possible to erect, at the present day, a tribunal like that of Solomon, in which might be decided the claims of nations contending for the maternity of steam navigation, on the evidence which each could give of the true affection of a mother, certain it is that the decision would not be favourable to Great Britain. Is it too late still to be just? Do our rulers preserve honours and emoluments only for the soldier and the political partisan? We confess we have little hope that they will correct the future from the past.

The nations that have urged exclusive claims to the invention of steam navigation, are the British, the Americans, the Spanish, the French, and the Italians. The Spanish claim is undoubtedly the oldest of all, though not the least ambiguous, and although it assigns a date to the invention older than any of the other claimants, the pretension itself was only put forth at a recent date. The document is curious.

*Spain.* In 1826, there was published by Thomas Gonzales, an ancient manuscript discovered among the state papers at Simancas, of which remarkable document the following is a literal translation.

" Blasco de Garay, a naval captain, proposed to the Emperor Charles V., in 1543, a machine for propelling vessels and fleets without sails or oars, even in a calm. In spite of the difficulty and paradoxical nature of this proposal, the Emperor ordered an experiment to be made at the port of Barcelona, which was carried into effect on the 17th day of June 1543. Garay did not wish entirely to reveal his discovery; nevertheless, it was manifest during the experiment, that it consisted of a large caldron of boiling water and of moving wheels on either side of the vessel. The experiment was made on a vessel of 200 tons, called the Trinity, carrying corn from Colibre to Barcelona, commanded by Captain Pedro de Scarza. By order of Charles V., the following individuals assisted at the experiment, Don Henri de Tolado, the Governor, Don Pedro de Cardo, the Treasurer Ravago, the Vice-Chancellor, and the Keeper of the Records.

" In the reports made to the Emperor and Prince, general approbation was given to this ingenious experiment, particularly on account of the promptitude and facility with which the vessel was turned. The treasurer Ravago, who was opposed to the scheme, said that it would go two leagues in three hours, that the machine was too complex and expensive, and that there was danger of bursting the caldron. The other commissioners declared, that the ship came round as rapidly as vessels propelled in the ordinary way, and made a league an hour at least.

" When the trial was finished, Garay removed all the machinery with which he had furnished the vessel, the wood part only was laid up in the arsenals at Barcelona, and the rest he retained to himself.

" Notwithstanding the opposition of Ravago, Garay's invention was approved of, and had not the expedition in which Charles V. was engaged interfered, he would undoubtedly have given it encouragement, and even in these circumstances, the author was rewarded by a step in promotion, and a sum of two hundred thousand maravedies, had all his expenditure defrayed from the treasury, and received several other honours."

This is certainly a very extraordinary document. Both its authenticity and its genuineness have been called in question. Without however doubting its title to implicit evidence, thus much is plain—that the invention was kept secret by the inventor, and that it died with him. Society owes him no gratitude who bequeathed her no benefit, and, it is manifest, that it is not in any degree to the ingenuity of that Spaniard, nor the liberality of the Spanish government, that we owe our present system of steam navigation. Had this document been published prior to the introduction of steam navigation, instead of making its first appearance in the second quarter of the 19th century, it might, in that case, have performed the important office of suggesting the application of the force of boiling water to mechanical uses and to navigation.

This Spanish document serves the very important purpose of enabling the historian at once to dispose of the several competing claims to the honour of having invented the art of steam navigation. If the first *suggestion* of steam navigation, in a printed document publicly sold in shops, is to be held as establishing a title to the honour of inventor, then, undoubtedly, Jonathan Hulls, who published his tract with drawings, and a full exposition of his plans for steam navigation, at London in 1736, price 6d., from which we are about to give extracts, is the inventor, and England bears away the palm; unless, indeed, as was once gravely argued with the author by an American, the fact of his bearing the characteristic cognomen of Jonathan, is to be held as conclusive proof of his having been a native of the New World. And if, on the other hand, it is the first attempt in actual experiment without regard to ultimate usefulness, which is to be held as the only legitimate ground of claim, then undoubtedly Captain Blasco de Garay is its author, and Spain the country which has conferred upon the world that boon by which she herself has been the least to benefit. But if neither of these grounds is to constitute the claim, and the final successful construction of a steam vessel on the same principle as the modern steam ship, serving as a pattern from which others have copied, and from which directly and immediately the actual trading steam ships of the country are derived, is to be the legitimate place, then most unquestionably on this, the only fair ground of claim to the gratitude of the civilized world, Miller, Symington and Taylor are the three equal stars of the constellation to which the homage of posterity is to be paid.

Notwithstanding the impregnable position which Great Britain has thus attained, as having conferred upon the world the inestimable blessings that have been diffused by means of mechanical navigation; notwithstanding, that she who gave birth to steam navigation has also brought it to maturity, and that it is from her directly that other powers of Europe have obtained those scanty supplies of steam ships of which they have possessed themselves; notwithstanding also that it is to Great Britain that one half of the world owes the means of Transatlantic steam communication, means which it is still incapable of equalling or even imitating; notwithstanding the early consent of nations, and the evidence of plain facts that Britain has not only originated, but carried to the utmost perfection, not only steam navigation, but the very steam-engine itself, and all its other applications, and that in virtue of these applications it still stands at the head of nations—notwithstanding all this, there are men who, in the desire for national popularity, have actually endeavoured to turn aside the straight-forward candour with which other nations at first acknowledged their obligations, and have attempted by partial statements of truth and false inference from facts, to undermine the reputation of Great Britain, and disavow the source to which they owe so much present greatness.

*Pretensions of America and Britain to the invention of steam navigation.*—The American treatise on the steam-engine by Professor Renwick, exhibits in the following passage one of these very unworthy attempts to misrepresent the plain historical truths of the invention of steam navigation. Speaking of Jonathan Hulls's pamphlet on steam navigation, published in 1737, he says, " English authors have *raked up from oblivion* a patent granted in 1736 to a person of the name of Jonathan Hulls.* He, however, never made an acting

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* Jonathan Hulls, on the 21st of December 1736, obtained a patent, to endure for fourteen years, for what may, without any impropriety, be called a *steam boat.* The letters patent and a description of this boat, illustrated with a plate, are contained in a tract, published by Hulls in 1737, under the following title : *A Description and Draught of a new invented Machine for carrying Vessels or Ships out of or into any Harbour, Port, or River, against Wind and Tide or in a Calm.*

He introduces his description by a concise view of the principles of experimental philosophy ; in which he observes, (p. 39,) " If a person were to descend to the bottom of a well of water, his body would be pressed the same as if he descended the same depth into the sea ; for there is the same pressure against a pool-head as there is against the sea bank at the same depth, as hath before been demonstrated.

" Thus I have endeavoured to explain the nature of the pressure of the air on other bodies, by comparing it with other fluids that are visible to our eye, as mercury, water, &c., and, since the pressure is so very great, it is the more fit to be applied to a purpose wherein all sorts of manual operations are insufficient. For model of his invention, and the prime mover itself was at the time in a state far too imperfect to have permitted its being successfully used in the manner proposed by Hulls. So far then from classing this among *ingenious* and *profitable* improvements, we should rather be inclined

this present undertaking cannot be supposed to be done by strength of men or horses, or any machine driven by either.

" The atmosphere being of great weight, and striving to get in where there is a vacuum, I shall endeavour to show how this vacuum is made, and in what manner this force is applied to drive the machine.

" In some convenient part of the tow boat there is placed a vessel about two-thirds full of water, with the top close shut; this being kept boiling, rarefies into a steam. This steam being conveyed through a large pipe into a cylindrical vessel, and there condensed, makes a vacuum, which causes the weight of the atmosphere to press on this vessel, and so presses down a piston that is fitted into this cylindrical vessel, in the same manner as in Mr Newcomen's engine, with which he raises water by fire.

" It hath been already demonstrated, that a vessel of thirty inches diameter, which is but two feet and an half, when the air is driven out, the atmosphere will press on it to the weight of four tons, sixteen hundred weight, and upwards; when proper instruments for this work are applied to it, it must drive a vessel with a great force.

" The bigness of the machines may be proportioned to the work that is to be performed by them; but, if such a force as applied in this first essay be not sufficient for any purpose that may be required, there is room to make such addition as will move an immense weight with tolerable swiftness.

" It is my opinion it will not be found practicable to place the machine here recommended in the vessel itself, that is to be taken in or out of the port, &c., but rather in a separate vessel, for these reasons:—

" 1st, This machine may be thought cumbersome, and to take up too much room in a vessel laden with goods, provisions, &c.

" 2d, If this machine is put in a separate vessel, this vessel may lie at any port, &c. to be ready on all occasions.

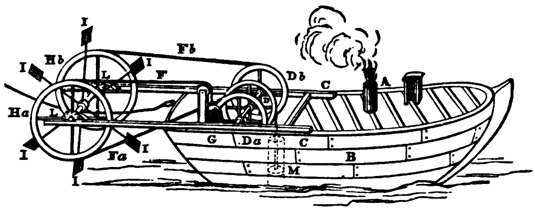
to rank it among those, which, from their obvious impracticability, merit the oblivion into which they instantly fall."

We cannot refrain from characterizing this passage as ungenerous and unjust in the extreme, and perfectly un-

"3d, A vessel of a small burthen will be sufficient to carry the machine to take out a large one.

"4th, A vessel will serve for this purpose for many years, after she is thrown off, and not safe to be taken abroad."

The passages above quoted are followed by the *Explanation of the Machine*. The Figure to which this *Explanation* refers, is copied from that given by Hulls.



"*A* represents the chimney coming from the furnace.

"*B*, the rope attached to the vessel to be towed.

"*CC*, Two pieces of timber, framed together, to carry the machine.

"*Da*, *D*, and *Db*, are three wheels on one axis, to receive the ropes *M*, *Fa*, and *Fb*.

*Note.*—*M* is the same rope that goes into the cylinder.

"*Ha* and *Hb* are two wheels on the same axis with the fans *IIIIII*, and move alternately in such a manner, that when the wheels *Da*, *D*, and *Db*, move backward or forward, they keep the fans *IIIIII* in a direct motion.

"*Fb* is a rope going from *Hb* to *Db*, that, when the wheels *Da*, *D*, and *Db*, move forward, moves the wheel *Hb* forwards, which brings the fans forward with it.

"*Fa* is a rope going from the wheel *Ha* to the wheel *Da*, that when the wheels *Da*, *D*, and *Db*, move forward, the wheel *Ha* draws the rope *F*, and raises the weight *G*, at the same time as the wheel *Hb* brings the fans forward.

"When the weight *G* is so raised, while the wheels *Da*, *D*, and worthy both of professor Renwick and of America. Professor Renwick has written a very excellent and meritorious work on the steam-engine, which has many scientific discussions and practical investigations, that do credit to his sagacity and science, and we admit most willingly

*Db*, are moving backward, the rope *Fa* gives way, and the power of the weight G brings the wheel *Ha* forward, and the fans with it, so that the fans always keep going forward, notwithstanding the wheels *Da*, *D*, and *Db*, move backwards and forwards, as the piston moves up and down in the cylinder.

" *LL* are teeth for a catch to drop in from the axis, and are so contrived that they catch in an alternate manner, to cause the fans to move always forward, for the wheel *Ha*, by the power of the weight *G*, is performing its office, while the other wheel *Hb* goes back in order to fetch another stroke.

" *Note.*—The weight *G* must contain but half the weight of the pillar of air pressing on the piston, because the weight *G* is raised at the same time as the wheel *Hb* performs its office, so that it is, in effect, two machines acting alternately by the weight of one pillar of air of such a diameter as the diameter of the cylinder is.

" If it should be said that this is not a new invention, because I make use of the same power to drive my machine that others have made use of to drive theirs to other purposes; I answer, the application of this power is no more than the application of any common and known instrument used in mechanism for new invented purposes." P. 43.

This Explanation is followed with the annexed " *Answers to some Queries that have been made concerning the possibility and usefulness of this undertaking.*"

QUERY I.

" Is it possible to fix instruments of sufficient strength to move so prodigious a weight as may be contained in a very large vessel?

" Answer. All mechanics will allow it is possible to make a machine to move an immense weight, if there is force enough to drive the same; for every member must be made in a proportionable strength to the intended work, and properly braced with laces of iron &c., so that no part can give way or break, if the braces, &c., necessary for this work had been put into the draught it would have been so much crowded with lines, that the main instruments could not be so well perceived.

that many important subjects discussed in his work have too little attracted the attention of British engineers and authors. We are quite ready to grant also, that steam boats first turned out "profitable" speculations in America; but to say that we have "*raked up* Hulls's patent from oblivion"—to say that an invention of which a full

QUERY II.

"Will not the force of the waves break any instrument to pieces that is placed to move in the water?

"Answer. *First,* It cannot be supposed that this machine will be used in a storm or tempest at sea, when the waves are raging; for, if a merchant lyeth in a harbour, &c., he would not choose to put out to sea in a storm, if it were possible to get out, but rather stay until it is abated.

"*Secondly.* When the wind comes ahead of the tow boat, the fans will be protected by it from the violence of the waves; and when the wind comes side-ways, the wind will come edge-ways of the fans, and therefore strike them with the less force.

"*Thirdly.* There may be pieces of timber laid to swim on the surface of the water on each side of the fans, and so contrived as they shall not touch them, which will protect them from the force of the waves. Up inland rivers, where the bottom can possibly be reached, the fans may be taken out, and cranks placed at the hindmost axis, to strike a shaft to the bottom of the river, which will drive the vessel forward with the greater force.

QUERY III.

"It being a continual expense to keep this machine at work, will the expense be answered?

"Answer. The work to be done by this machine will be upon particular occasions, when all other means yet found out are wholly insufficient. How often does a merchant wish that his ship were on the ocean, when, if he were there, the wind would serve tolerably well to carry him on his intended voyage, but does not serve, at the same time, to carry him out of the river, &c. he happens to be in, which a few hours' work of this machine would do. Besides, I know engines that are driven by the same power as this is, where materials for the purpose are dearer than in any navigable river in England; therefore, experience demonstrates, that the expense will be but a trifle to the value of the work per-treatise with·detailed plates of the machinery, and an exposition of the mechanical principles of the steam-engine, almost as full as that of the Professor of natural and experimental philosophy in Columbia college himself in his own treatise—to say that an invention, the description of which was printed and sold in the pamphlet shops for sixpence, and which, even now is by no means so rare in Great Britain as the Professor's own most excellent treatise—to say that such an invention has been "raked up from oblivion," as if for the paltry purpose of defrauding America of some well merited honour, is at once uncandid, ungenerous, and incorrect. That his invention was "ingenious," nobody ever doubted who had read the book, or was capable of understanding it—that it was "profitable" to the inventor, we do not mean to assert, for inventors have almost always been not only the victims of detraction, like that of Professor Renwick, but of still more deeply consuming poverty. But we should not have expected a countryman of Oliver Evans to have taunted an ingenious, but probably poor man, with not having converted his talents into a pecuniary gain.

This "obscure person, of the name of Jonathan Hulls," was by no means so ignorant or incompetent to the perfection of this admirable invention, as Mr Renwick would have his countrymen to suppose. This "obscure person" appears, by his work, to have been deeply versed in the writings of Archimedes, Ctesibius, and Hero. He illustrates the doctrines of statics by appropriate experiments; he anticipates the very objections which Professor Renwick elsewhere brings against his invention, showing that it was neither absurd nor impracticable, but required only to be well executed in

formed by those sort of machines, which any person that knows the nature of those things may easily calculate."

order to prove useful. After explaining fully the doctrine of atmospheric pressure, he says, " the atmosphere being of a great weight, and striving to get in where there is a vacuum, I shall endeavour to show how this vacuum is made, and in what manner this force is applied to drive the machine. In some convenient part of the tow-boat there is placed a vessel about two-thirds full of water, with the top close shut. This being kept boiling, rarefies into a steam. This steam being conveyed through a large pipe into a cylindrical vessel, and there condensed, makes a vacuum, which causes the weight of the atmosphere to press on this vessel, and so carries down a piston that is fitted into this cylindrical vessel, in the same manner as in Mr Newcomen's engine, with which he raises water by fire. It hath already been demonstrated that a vessel of thirty inches diameter, when the air is driven out, the atmosphere will press on it to the weight of four tons sixteen hundred weight and upwards; when proper instruments for this work are applied to it, it must drive a vessel with great force."

Hulls thus gives a full description of all the mechanism of his steam boat in a form which, although not so simple as the present method of moving the paddle wheel, must be admitted to be at once ingenious and practicable. He next considers the comparative advantage of having the steam machinery in the ship itself, or in a separate tow-boat; but presses the latter for many reasons, which he adduces.

As if anticipating the objections of such men as Professor Renwick, he proceeds to give answers to " Queries respecting the Possibility and Usefulness of his Underdertaking;" and on this subject his views must be admitted to be distinguished by sound practical common sense, unmixed with exaggeration. 1. He proposes for strength to brace the whole with iron; 2. He discusses the means of avoiding the injurious action of the waves; 3. He discusses the question of L. S. D. most conclusively; then "query the third, it being a continual expense to keep this machine at work, will the expense be answered?" "The work to be done by this machine will only be upon particular occasions, when all other means yet found out are wholly insufficient. How often does a merchant wish that his ships were on the ocean, when, if he were there, the wind would serve tolerably well to carry him on his intended voyage, but does not serve at the same time to carry him out of the rivers, &c. he happens to be in, when a few hours' work of this machine would do? Besides, I know engines that are driven by the same power as this is, where materials for the purpose are dearer than in any navigable rivers in England; therefore experience demonstrates that the expense will be but a trifle to the value of the work performed by those sort of machines." Such is the "ingenious and profitable" scheme which the able Professor of Columbia college asserts that the English have raked up from oblivion, but which he conceives to be unworthy of note from its obvious impracticability.

He might with some truth have taunted the English with, first, allowing a valuable invention to lie so long unadopted, and in all probability bringing its author into disrepute and poverty while he lived, and then only doing that justice to his memory which they should have done to himself; but it was not necessary for the credit of America to inflict an injury upon the memory of a Briton who had advanced too far before the age he lived in, but who will go down to posterity as the first inventor of an ingenious and practicable mechanism for propelling vessels by a condensing steam-engine and by paddle wheels, being the very means at this day most profitably employed in America, Great Britain, and the rest of the world. Such was Jonathan Hulls. We can only palliate Mr Renwick's offence against the justice and generous candour of philosophical history, by supposing him altogether unacquainted with the works of Hulls. Not satisfied, however, with contemning Hulls, (who, by the bye he asserts, *never* actually constructed a model of his invention, although there is not only no proof that he never did so, but a strong presumption, on the contrary, that his boat was actually constructed and usefully employed,) not satisfied with this one act of injustice, Professor Renwick seems determined to run a muck against the whole race of non-American inventors. He next attacks the knight of Dalswinton, and asserts that his second vessel, one which went at the rate of seven miles an hour, "was an absolute failure!" while, a few pages on, he vaunts the wonderful success of Fulton, who, thirteen or fourteen years afterwards, built a boat in imitation of this, which first broke its back and went to the bottom, and then, on being reconstructed, went a short distance at some three miles an hour; this he calls perfect success! and the Scotch experiment, fourteen years previous, at nearly seven miles an hour, he calls "an absolute failure!" What must have been Professor Renwick's own opinion of his cause, when he could get up no statements more consistent than these

We have already seen that, after experiencing the unfortunate denouement of his own experiment, Mr Fulton came to Scotland, and having travelled six miles an hour in Symington's boat, and been allowed to avail himself of her minute examination, that his conviction of the success of Mr Symington's invention was so complete, as, in spite of his own previous failure, to have led him at once to order an engine *in Britain* for America. We have already seen all this, which Renwick does not, because he dare not, attempt to deny ; but he endeavours to evade the force of that plain statement, by attempting to confuse dates in a manner so impotent, as plainly to prove that nothing less than an actual falsifying of documents could prove his point. " If," says he, " Fulton saw Symington's boat in 1801, he returned to France" (to make his own wretched trial) " with his previous impressions in favour of paddle wheels very much weakened; if not until 1804, he had already performed more than Symington." There never was more contemptible or shallow sophistry; it should read thus—If Fulton saw Symington's boat going six miles an hour in 1801, and afterwards made his own experiments in France, where his boat was first taken to the bottom, and broken to pieces by the mere weight of the engine, and after being rebuilt was not able to do three miles an hour; in this case, how utterly inferior is the imitator proved to have been to the man whom he tried to copy!—If it was not until 1803 or 1804 that he visited Symington's boat, he must have been at once convinced that his former failure arose from his own incompetency to the task of reinventing what had long before been so well accomplished by Symington. Why did not Renwick tell his readers that Fulton, after his most minute examination of Symington's engine, after getting an admirable engine from Watt and Bolton, and after spending three or four years more in perfecting his imitation, did not even then succeed in doing so much, by at least one mile an hour, as Symington had already done in his presence so long before?

But it is plain that what the Professor of Columbia college wanted, was to place his countryman on a pedestal, where an American might have the gratification of doing homage for one of his greatest national blessings, to an American rather than a Briton; for, in order to deify him still more completely, he says of Fulton—whose boat (he takes care never to tell us) had broken through the middle, and not gained four miles an hour—that it was then, (after the boat had gone to the bottom?) as afterwards, remarkable that, by a sound view of theoretic principles, the single boats of Fulton always presented *the speed which he predicted*, at the moment of planning them ! ! ! To show, in conclusion, how far the *amor patriæ* has carried the author of the American Treatise on the Steam-Engine from the truth, we have only to quote one sentence on the subject referred to, from the Life of Fulton, published in America by one of his own countrymen, who had fuller access to all his private documents, and who exhibits, with every proper love of his country, and all just respect for the subject of his pen, an equal love of consistency and respect for truth. "The experiment in France and the *velocity* of the Clermont, *fell so far short of his estimates*, that," &c. So much for Fulton's infallibity, and Renwick's fidelity.

America, therefore, owes to Fulton the debt of having benefited her by the early introduction of the invention of Miller, Taylor, and Symington, into a country whose peculiar geographical connexions rendered this gift of the utmost importance to her prosperity.

Another claim to the invention has been adduced by a nation we should least have suspected, the Italians. In a work entitled, "Elements of Experimental Physics," published at Florence in 1796, we find the following passage:—"James Watt was the inventor of steam-engines in England in the year 1787, although many experiments of a similar nature had been made previously to that time. An Italian, Serapino Serrati, was, however, the first, not only to conceive the design of a steam boat, but also to place one upon the river Arno, which runs through Florence." We have no means of testing the value of this assertion, but, like the Spanish claim, it may either be true or untrue, without affecting the history of steam navigation, as it is unquestionable that whatever merit they may have individually possessed as experiments, our present system of steam navigation has been in no way derived from them.

The French nation has founded a claim to the invention of steam navigation, upon the ground that Mr Perier, in 1775, and M. de Jouffroy, in 1781, made experiments in steam navigation: that they, however meritorious, did not in any way contribute to the production of our modern system of steam navigation, is enough to deprive them of extended notice in our history of that art.

## CHAPTER IV.

### *On the progress of Steam Navigation in America and Europe, from its introduction to its present condition.*

We have seen that the experiments of Miller, Symington, and Taylor, had brought steam navigation to so great perfection that nothing remained to be done except the adoption of it by mercantile men for the purposes of gain and of commercial intercourse. Livingstone and Fulton formed the first commercial steam navigation in America, on the Hudson, and Bell in Europe, on the Clyde, both having obtained their knowledge directly, immediately, and exclusively, from the experimental triad of Dalswinton.

It is a little curious that, although Fulton was first in America, and Bell in Europe, to avail themselves of the advantage of steam navigation, it was in both cases *non longo intervallo distanti.* Fulton was first in the race only by a few days, and Bell by a few months.

R. L. Stevens of Hoboken, is probably the man to whom, of all others, America owes the greatest share of its present highly improved steam navigation. His father was associated with Livingstone in his experiments, previous to the connexion of the latter with Fulton, and had persevered in his experiments during Livingstone's absence in France. Fulton's boat, however, was first ready, and obtained an exclusive privilege from the State of New York. Being excluded from the Hudson and all waters of that State, Stevens conceived the bold idea of taking his steam boat by sea to the Delaware. Stevens was thus the author of steam navigation in the open sea.

From various competent sources, we have been assured that Mr Stevens, who now enjoys a large fortune, the result of his labours in steam navigation, is a man of much original talent, of considerable scientific acquirements, and of great practical skill. To him America owes both the modification of steam-engine and construction of vessels by which the highest speed is accomplished.

Instead of changing altogether the form of Mr Watt's engine as we have done, for the purpose of stowing it below the decks of our steam-vessels, he retained the long working-beam on deck, and, only removing the cistern of cold water from around the condenser, and using a large jet of injection within, he placed the steam-engine of Watt on the bottom of his vessel, much in the same way as it would be placed in a cotton-mill, or to drive a coal-gin, having the great working-beam performing its oscillations aloft, far above the height of the paddle boxes, and indeed half-way up the chimney.

Another change introduced by Stevens into Watt's engine, in which it differs from our marine engine, is the use of upright guides for the piston-rod, instead of the old parallel motion. This was rendered necessary by the next peculiarity.

A peculiarity of great importance is the introduction of a very long stroke, and the use of steam working expansively in the cylinder. With this a change of great value is necessarily introduced, namely, a long crank, *i. e.*, longer leverage for the power of the steam in comparison with the diameter of the paddle wheel.

The divided paddle wheel is another of Stevens' inventions, whereby the resistance of the water to the paddle boards is rendered more uniform, and the concussions of the common wheel are avoided.

Stevens at a very early period adopted the method of surface, or dry condensation, as it is called, where the extended surface of a condenser, surrounded by cold water, is used to supply the place of injecting a stream of cold water among the steam. He used for this purpose copper tubes, copper plates, and other apparatus since tried in this country; but, like most other engineers who have tried this method since the time of Watt, he found it disadvantageous, and reverted to condensation by jet.

Stevens, more than any one, has improved the shape of the American steam vessels. The full round bows and sterns of Fulton's boats, which were mere boxes sharpened a little at both ends, drove before them so large a heap of water as to limit their speed to about nine miles an hour. He extended the length of his vessels to eight or ten times their beam, and giving them a fine entrance and a fine run, rose at once from nine to thirteen miles an hour. Directing his attention to pushing the water aside, rather than carrying it under the vessel, he succeeded in rendering the resistance of the water, and its disturbance by the boats, comparatively small.

A principle applied to steam navigation in America, much more than in Britain, is one great cause of the superiority in speed of American vessels. We allude to the system adopted so generally in Cornwall pumping-ing engines of working steam expansively. The great practical advantage of doing so was first introduced in America by a Mr Adam Hall, director of the West Point foundery, and by him communicated to Professor Renwick, who, by his treatise, has contributed much to the advancement of steam navigation in America. In order to show the advantage of this method, Professor Renwick states, that by loading a safety-valve to fifty-seven pounds, and cutting off the steam when the cylinder has been filled to one-eighth of its length, the power will be doubled, and at the same time a saving of fuel be effected amounting to two fifths. The use of steam of a higher pressure than the atmosphere, acting expansively through a large part of the stroke of the steam-engine, was discovered, though erroneously conceived and explained, by Wolf. There is no difference between the mode of applying this principle in American engines from that used in Cornwall.

The method of working expansively with a long-stroked engine, and the use of large equilibrium valves and passages, has allowed and carried into effect a high velocity of piston. We have the means of knowing that there are many vessels in America at this moment, whose pistons, instead of travelling at the average rate of 220 to 250 feet a minute, as usual in this country, move at double, and even more than double that rate. The cylinders are sometimes, in such cases, as much as three diameters in length.

We have already mentioned the great length of American steam vessels in proportion to their breadth. The hull, at the same time, is built with attention to lightness rather than solidity. To support the great weight of machinery and boilers in the centre of the vessel, the American builders appear to have regarded their vessel as a sort of wooden bridge, resting on two liquid buttresses towards each extremity, and loaded with a great weight in the centre; and in this view they seem to have introduced into their vessels all the mechanical structures which the resources of terrene-carpentry and civil engineering present in the construction of arches, wooden trusses, and iron suspension bridges, which extend along the vessel, transferring the proper proportion of the strain to those parts of it which are most distant from the load. These arches and tensile structures sometimes rise high above the deck of the vessel, and give to the vessels a wonderful rigidity. Vessels of more than 200 feet long are sometimes made entirely of thin plank crossed in three layers, and, without any timbers, are yet able to support both the weight and effort of five or six hundred horse-power machines, by means of their judicious construction.

Our own island kingdom has been the scene of all the improvements made on steam navigation in Europe. We believe that there is not in the most improved European steam ships of the present day a single item of construction which is not wholly British in its origin.

America is distinguished by its improvement of inland steam navigation. The nature of the country determined the efforts of invention in that direction, as in our own country the position of our ocean island decided our attention to the navigation of the deep sea; and by the success of our efforts we are now distinguished above the rest of the world immeasurably.

We naturally look to the birthplace of the steam-engine and steam navigation for the improvement of steam navigation, and we accordingly find it making rapid progress on the river Clyde, in North Britain.

Bell having introduced steam navigation into commercial use, by building the Comet in 1812, was quickly followed by numerous speculators in steam boats on that river: in 1813, John Thomson, his former *collaborateur* in experiment, completed his vessel, the Elizabeth, which we have already described; and having given her more power and a better proportion and construction, at once outstripped, in his turn, Mr Bell, and found his boat a successful speculation.

The third Clyde steam vessel was built, like the two former, by the Messrs Wood of Port Glasgow, near Greenock, for a Mr Robertson, an engineer of Port Glasgow. Her dimensions were seventy-six feet long on deck, fourteen feet beam, and sixty-nine tons measurement. Her power was fourteen horses; speed six miles an hour.

The fourth steam vessel, the Glasgow, was also built by the Messrs Wood of Port Glasgow, the engines by Mr Cook of Glasgow. She was intended to carry goods as well as passengers, and was seventy-two feet long, fifteen feet beam, seventy-four tons measurement, and sixteen horse power. This vessel belonged to the first of a species of associations since become so common, a joint-stock company for steam navigation; and set the example of being thoroughly mismanaged. This vessel was launched in 1813, and was moderately sharp, but was afterwards improved by lengthening the bow five feet, and giving it greater sharpness.

About 1814, two vessels, the Princess Charlotte and the Prince of Orange, built by a person of the name of Muir, were tried on the Clyde. Messrs Watt and Bolton were the engineers; but from some cause these vessels were unsuccessful. Next year the same engineers placed their engines in a vessel named the Caledonia, built by the Messrs Wood, ninety-five feet six inches long, fifteen feet beam, 102 tons measurement, and having two engines of sixteen horse power. This vessel was more successful.

Such were the early vessels, of small dimensions, a low proportion of power, and little speed.

From the commencement of steam navigation in Great Britain, no great stride appears to have been made until the year 1818, when Mr David Napier, the engineer, entered on the construction and improvement of steam navigation. We believe, that from the year 1818 until about 1830, David Napier effected more for the improvement of steam navigation than any other man. It is necessary to distinguish betwixt him and Mr Robert Napier, whose successful efforts in steam navigation are of later date.

It is to Mr David Napier that Great Britain owes the establishment of deep sea communication by steam vessels, and of post-office steam packets. Previous to his time, steam vessels ventured rarely, and only in fine weather, beyond the precincts of rivers and the coast of friths. Mr David Napier adventured at once to establish regular communication between Britain and the surrounding countries, Ireland and France, by steam-vessels plying even during the stormy months of winter. It is said that the following is the manner in which he first essayed his arduous attempts. Not long after the introduction of steam navigation on the river Clyde, he had entertained the idea of establishing steam communication on the open sea; and as a first step, he endeavoured to ascertain the amount [illegible] difficulties to be encountered. For this purpose he took a place at the stormy period of the year in one of the sailing packets which then formed the only means of intercourse between Glasgow and Belfast, and which then required often a week to accomplish what is done by steam in nine hours. The captain of the packet in which he sailed, remembers distinctly a young man, whom he afterwards knew as Mr Napier, being found, during one of the winter passages to Belfast, constantly perched on the bows of the vessel, and fixing an intent gaze on the sea when it broke on the side of the ship, quite heedless of the waves and spray that washed over him. From this occupation he only ceased at intervals, as the breeze freshened, to ask the captain whether the sea was such as might be considered a rough one, and being told that it was by no means unusually rough, he returned to the bows of the vessel and resumed his study of the waves breaking at her stem. Some hours after, when the breeze began to freshen into a gale, and the sea to rise considerably, he again enquired of the captain, whether now the sea might be considered a rough one, and was told that as yet it could not be called very rough. Apparently disappointed, he returned once more to his station at the bows, and resumed his employment. At last, however, he was favoured with a storm to his contentment; and when the seas, breaking over the vessel, swept her from stem to stern, he found his way back to the captain and repeated his enquiry; do you call it rough now? On being told that the captain did not remember to have faced a worse night in the whole of his experience, the young man appeared quite delighted, and, muttering as he turned away, " I think I can manage, if that be all," went down contentedly to his cabin, leaving the captain not a little puzzled at the strange freak of his passenger. Napier saw the end of his difficulties, and soon satisfied himself as to the means of overcoming them.

His next enquiry regarded the means of getting through the water with least resistance. To determine this, he commenced a series of experiments, with models of vessels on a small tank of water; and found, in a short time, that the full round bluff bow adopted for sailing vessels, was quite unsuitable to speed with mechanical propulsion of a different nature. He was soon led to adopt the sharp fine wedge-like entrance by which the vessels built under his superintendance were so much distinguished.

In 1818, Mr David Napier established between Greenock and Belfast, a regular steam communication, by means of the Rob Roy, a vessel built by Mr William Denny of Dumbarton, having about 90 tons burden, and thirty horse power. She plied two winters between these ports with perfect regularity and success, and was afterwards transferred to the English Channel to serve as a packet between Dover and Calais.

Having thus acquired dominion of the open sea, Mr Napier was not slow to extend it; in 1819, the Messrs Wood built for him the Talbot of 150 tons, with two of Mr Napier's engines, each of thirty horse power; this vessel was by far the most perfect vessel of her day, in all respects, and formed a model which was long in being surpassed. The Talbot plied between Holyhead and Dublin, and was the means of conferring on Ireland the advantage of a direct, certain, and rapid communication with England. The Talbot was succeeded by the Ivanhoe, built by Mr Scott of Greenock, of 170 tons burden with Mr Napier's engines of sixty horse power in the aggregate, and she also long continued the best packet on the station between Holyhead and Dublin.

At the same time that Mr Napier was thus engaged in conferring on the public the benefits of the post-office steam packet system, he also established the first line of commercial steam ships, on a station which ever since that time has continued to be occupied by the finest, most powerful, expert, and fastest steam packets in Europe—the station between Liverpool, Greenock, and Glasgow. The Robert Bruce of 150 tons, built by the Messrs Wood, with Mr David Napier's engines of sixty horse power; the Superb of 240 tons, by Mr Scott, with Mr Napier's engines of seventy horse power; the Eclipse, by Mr Steel, of 140 tons burden, with Mr Napier's engines of sixty horse power—all these were established as regular deep sea traders, under the direction of Mr David Napier, before the year 1822. They were all vessels of a much stronger hull, a better form, and more correct proportion of parts than any others; and in these three years, from 1818, the art of steam navigation had received in the Clyde an extension and perfection that rendered it an object of great national importance.

From this period, the navigation of the deep sea underwent great and rapid improvement. The construction of the James Watt, steam vessel, appears to have formed a great step in steam navigation. This vessel was completed under the superintendance of Mr Brown, of Watt and Bolton, in 1822, to sail on the station between Leith and London. The vessel was built by the Messrs Wood, on the Clyde. It was of 448 tons measurement, and carried two engines, by Messrs Watt and Bolton, of 50 horse power each. This vessel, in beauty of form, strength of construction, and speed, was much before every vessel of her day, having a velocity of 10 miles an hour. She was remarkable for having engines on the second motion, that is to say, the paddles were not made to revolve directly by immediate connexion with the cylinder ; but the engines, first of all, produced revolution in an axis, from which the paddle shaft was propelled by toothed wheels, in such a manner, that the number of revolutions of the axis of the engine was greater than that of the paddle shaft. With the exception of her low proportion of power to tonnage, this vessel possessed almost all the qualities of the most improved vessel of the present day, and has served as the model after which the best sea-going vessels of the Thames were built. Her dimensions were 146 feet over all, 25 feet beam, and 448 tons measurement.

From the period of the construction of the James Watt, no change of great importance seems to have been made in steam navigation of the deep sea, until the construction of the United Kingdom, the first of the steamers now increasing so rapidly, and which we may designate the Leviathan class of steam ships. The United Kingdom was, properly speaking, a frigate—being a ship of 160 feet long, 26½ feet beam, and 200 horse-power. It was built by Mr Steele of Greenock, and the engines were constructed by Mr Napier. This vessel was by far the most splendid of her day, and gave rise to the large class of merchant ships of which the advantages are now reckoned so great, and which are now in common use.

Mr David Napier was also one of the first persons to introduce surface condensation in marine engines. He used it successfully in the Post-Boy, a steam vessel built by him in 1822. The condenser was made of a series of small copper tubes, through which the steam passed towards the air pump; and by a constant current of cold water encircling the pipes, the steam was cooled and returned into water, which was again sent into the boiler for conversion into steam, without being mixed with the cold salt water, which in the usual plan is injected into the condenser. But like Watt, Cartwright, and others, who have tried this system, both here and in America, the rapidity of condensation was not found sufficiently great, and he returned to the old system of condensation by jet. Some years afterwards, however, he again returned to this system, in peculiar circumstances which rendered it desirable; and, using flat plates, instead of tubes, he was more successful, and plied for years with no other condenser. But, like all the other cases where it has been introduced, the advantages of the system were not reckoned an equivalent compensation for its disadvantages. The plan of condensation by tubes, again introduced at a recent date by Mr Hall, has been tried in numerous vessels, in some of which it has been abandoned, and in others still continues to be employed.

The next change introduced very extensively into steam vessels by Mr David Napier, was the use of an upright, or vertical steam-engine, or engine of direct connexion. The first engine of Bell was, to some extent, a vertical engine, inasmuch as the axis of the cylinder and of the crank were placed in one vertical line, but there was no direct connexion between the crank and the piston rod to the paddle axle, the communication of motion to it being effected through the medium of toothed wheels. In the common or lever engine, the piston rod acts on a cross head, the cross head on side rods, the side rods on side levers, the levers on a cross-tail, the cross tail on the connecting rod, and the connecting rod on the crank pin, by which, through the axle, the paddle wheels revolve. In the engine of direct connexion, the side levers, and some other parts of the train of communication is removed by a device which enables the piston rod to be almost immediately attached by a connecting rod to the crank of the paddle shaft. This plan was early adopted by Mr Gutzmer of Leith, who built a vessel called the Athol, and another called the Tourist, on this principle; but his method, though very simple, was not applicable in ordinary cases with advantage, and Mr Napier made several modifications of the vertical engine, which appear to include all the best that have yet been introduced, although many appear to claim the invention. It does not appear ever to have been established, that the engine of direct connection is practicably preferable to the lever engine; but the plans of Mr David Napier appear to have been the best ever adopted.

Mr David Napier has now many years retired from connexion with steam vessels on the Clyde; but before he left it, much had been done for the advancement of steam navigation in Britain by his cousin, Mr Robert Napier of Glasgow, whose establishment has since become famous for the construction of engines of the most efficient action, which being, generally speaking, combined with a superior class of ships built by the Messrs Wood, have extended the fame of the river Clyde very widely, and have enabled steam to be used with a degree of confidence and regularity, which could scarcely have been anticipated even by the most sanguine. The Berenice, East India Company's vessels, the Perth, Dundee, London, and the British Queen and Halifax Transatlantic ships are the *chef d'œuvres* of Mr R. Napier, and have furnished us with some valuable plates of marine engines.

To the talent of Mr Maudslay of London, the present marine engine owes the introduction of that high degree of precision in its construction and details, which gives it so much durability and efficacy as a machine.

We have already stated, that a regular communication by steam was early established between Liverpool and the river Clyde. The establishment of this station has done much for the advancement of steam navigation, from the following reasons: it has afforded profitable employment to two wealthy companies, who, employing the most eminent steam-engine and ship builders for the construction of their ships, without regard to expense, have produced a class of vessels unequalled in the whole world. The two engineers who have been thus placed in competition, are Mr Robert Napier of Glasgow, and the Messrs Cairds of Greenock, and the builders, Mr Wood of Port Glasgow, and Mr Steel of Greenock. The contending parties have nearly alternately conquered; each effort being superior to the former, and both being the highest efforts of the skill, ingenuity, and taste of their respective authors. The Vulcan, John Wood, City of Glasgow, Commodore, and Admiral, are the *chef d'œuvres* of Messrs Napier and Wood; the Manchester, Eagle, Unicorn, Actæon, and Achilles, of Messrs Caird and Steel.

As an example of the high perfection to which these friendly contentions have brought mercantile steam navigation, we insert at the end of the volume a tabular extract from a document lately brought forward in a Post-office enquiry. That extract contains the time required by the Unicorn steam ship for each trip between Greenock and Liverpool, 220 miles, during twelve months, including winter, and shows how much may be done by good machinery in good ships, to obtain high regularity and great speed. It is plain from this document that the mail-coach is not more true to her time than this steam ship, and that a velocity of above eleven miles was kept up, under all variety of loading, in a vessel devoted principally to the transport (along with passengers) of heavy merchandise. The dates are from a register by Captain Main, her commander, now of the Achilles, and is of undoubted authenticity. The dimensions and some particulars of this vessel are given elsewhere.

From the table above alluded to, we find that this merchant vessel, with every different variety of lading, and being constructed for the express purpose of carrying heavy cargoes, performed all her trips without losing a voyage, during the whole winter and summer, at the average rate of more than eleven miles an hour, ($11\frac{351}{2861}$,) being 146 trips of 218 miles in $19\frac{87}{146}$ hours each. That of these, only seventeen were two hours more than that time, only six four hours more than that time; and that during the six summer months, not three of the passages exceeded that time by more than an hour.

This table will also serve to assist any one who desires to ascertain the duty that may be calculated on in like circumstances; only it is necessary to recollect that, besides the duty here exhibited, the vessel had at the end of a trip to navigate a shallow and uncertain channel in the River Clyde, to Glasgow, whence, after discharging and reloading, she had to find her way back to Greenock. In that period the vessel performed about 35,000 miles, and would have performed easily about 60,000 miles, had it not been necessary to ascend the Clyde, and experience the corresponding delays.

This vessel, the Unicorn, has, since the date referred to, crossed the Atlantic, to take part in the transport of the Transatlantic mails between Britain and Halifax.

It was at this station also, and by the vessels already named, that the great commercial advantages of a large proportion of power in steam ships, in proportion to tonnage, and also of employing a large class of ships in preference to smaller ones, was first ascertained and demonstrated—a principle even at this day too little understood as a practical maxim, but of which we give the full exposition in another chapter. It was found upon this station as a mercantile result, that a large proportion of power was the economical, as well as profitable, way of conducting the trade. That not only speed, certainty, and security were thus attained, but also efficiency and economy. A dogma the reverse of this was then generally, and is still, too extensively maintained.

Another class of steam vessels on the east coast of Scotland has also increased rapidly, and tended much to the advancement and improvement of steam navigation in Great Britain—that class of vessels communicating between Leith and London. One of the most celebrated and perfect of these is the Monarch, built from the lines of Mr Charles Wood of the Clyde, under the superintendence of Mr Brown, of Messrs Bolton, Watt, and Co., and having the engines of that firm. This admirable ship performed 120,000 miles without costing her owners more than the most trifling sum for repairs of any kind to her hull or machinery.

Aberdeen is connected by a fine class of steam ships with London, being the productions of the northern city, and exemplifying the largest class of ships. Dundee also possesses an almost unrivalled line of communication in the Perth, Dundee, and London, three sister ships of a large class, built by Mr Wood, and engined by Mr Napier on the Clyde.

Besides these, the steam ships of Great Britain, we might adduce the mighty improvements which have been exhibited in the navigation of the wide ocean, by ships that have gone out from her. The recent extension of Steam Navigation to the navigation of the high seas is destined to form an important epoch in the history of Steam Navigation, and we may add, of civilization. Its use in war may also be regarded as likely to introduce a revolution next in importance to the introduction of gunpowder, and attended with similar results. But these are changes in which we live, and which have scarcely gone into the history of the past.

*The following Table exhibits a comparative view of the Size and Power of six of the largest of the constructed Vessels for Transatlantic navigation.*

| Dimensions and Power. | NAME OF VESSELS. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | British Queen. | | President. | | New York. | | Great Western. | | Liverpool. | | Acadia.* | |
| | Ft. | In. | Ft. | In. | Ft. | In. | Ft | In. | Ft | In. | Ft. | In. |
| Length from Figure Head to Taffrail, | 275 | 0 | 273 | 0 | 235 | 0 | 240 | 0 | 234 | 0 | 228 | 0 |
| Length of Upper Deck,............. .... | 245 | 0 | 243 | 0 | 0 | 0 | 0 | 0 | 212 | 0 | 206 | 0 |
| Breadth within the Paddle-Boxes..,... | 40 | 0 | 41 | 0 | 36 | 6 | 0 | 0 | 35 | 4 | 34 | 4 |
| Breadth over all,.......................... | 61 | 0 | 68 | 0 | 60 | 0 | 57 | 0 | 58 | 4 | 56 | 0 |
| Depth of Hold,.............................. | 27 | 0 | 30 | 0 | 22 | 0 | 20 | 0 | 23 | 3 | 22 | 6 |
| Diameter of Paddle-Wheels,.......... | 31 | 0 | 30 | 0 | 0 | 0 | 0 | 0 | 28 | 0 | 28 | 0 |
| Diameter of Engine Cylinder,.......... | 6 | 5½ | 7 | 6 | 0 | 0 | 0 | 0 | 6 | 1 | 6 | 0 |
| Length of Stroke,.......................... | 7 | 0 | 7 | 6 | 0 | 0 | 0 | 0 | 7 | 0 | 6 | 10 |
| Power of Engines,........................ | 500 h. p. | | 600 h. p. | | | | 460 h. p. | | 450 h. p. | | | |

* The three other North American Royal mail steam-ships Britannia, Caledonia, and Columbia, are of the same dimensions as the Acadia.

## THE THEORY AND PRACTICE OF MODERN STEAM NAVIGATION.

There is perhaps no popular error more injurious to the welfare of a mechanical nation, like our own, than the notion that theory is opposed to practice; and there is no subject in which this error has ever been more disastrous than in steam navigation and naval architecture in general. It is by the combination of theory and practice that most is to be accomplished; and it may be hazarded as a general assertion, resting on all past experience, that the best promoters of the public welfare are—that theoretical man who has made himself best acquainted with the practice of his art, and that practical man who has acquired the greatest knowledge of its scientific principles. There is no art which does not attest this truth, and none attests it more than steam navigation. It is admitted, that out of every three steam vessels that are built, two fall very far short of fulfilling the intention with which they were constructed. We believe there is no error which it may be possible to commit in steam navigation, that has not already been perpetrated again and again.

To construct a perfect steam vessel, it is necessary first of all to make a perfect ship; secondly, to construct a perfect steam-engine, and boilers of a very complex description; thirdly, to apply a propelling apparatus of the most appropriate description; and finally, to combine all of these in a perfect and well proportioned whole. Now, to construct a perfect ship, is itself a problem of the highest order, requiring a combination of the most profound resources of analysis, with the highest practical sagacity; a problem on which the reasoning of the mathematician, and the tact of the artist, have long been engaged, with few examples of complete success. To construct a sufficient, effective, powerful, durable, and safe engine and boilers for marine purposes, is a problem more easy, yet one in which there has been encountered continual failure. Then, the means of propelling the vessel over the element on which it floats, give rise to questions in the resistance of fluids which all the resources of hydrodynamic science, in the hands of the ablest mechanical philosophers of the last century, have failed to resolve. Then, last of all, the combination of all of these together, in the best possible way to bring about the precise effect desired, is a problem still more arduous; and all the skill of the analyst, the geometer, the mechanical philosopher, of the naval architect, the engineer, the mechanic, and the sailor, if combined in a single individual, or concentrated on a single object, are not more than sufficient to the arduous task of directing the wealth, enterprise, and resources of this country, in the attempt to render available to her own prosperity, and the interests of the human race, this most admirable of all her creations.

In the following enquiry, we shall soon see that neither practical experience without systematized knowledge, nor superficial theory ignorant of practical wants and practical means, will suffice to ensure success. Both physical science and practical sagacity will, in the art of steam navigation, find enough to exhaust their united resources.

We regret that we cannot record in the present work, that at this day the science of steam navigation is constructed and can be presented to our readers. Even the elementary principles of hydrodynamics are yet to be learned, before we can apply them to the ends of steam navigation. What seems the law of a fluid to-day, to-morrow shows to be a plausible fiction, or doubtful verisimilitude. How then can it be expected that a science should be determined, when its very foundations are yet to be laid? We shall, however, endeavour to generalize what we with certainty know, convinced that a clear statement of our ignorance is often the stepping-stone to truth. The steam ship consists of three integrant parts: the marine-engine, with its boilers, by which the moving power is furnished; the propelling apparatus, by which it is rendered locomotive; and the ship itself, which contains both. We shall consider each apart, and then their combination.

*The Marine Steam-Engine.*—The marine steam-engine is of a structure more complex than the common fixed steam-engine, inasmuch as its function is locomotive, and it differs from a land-engine in those peculiarities which adapt it to the unstable nature of its support. He who looks at the ponderous masses of matter that form and sustain the shock of a powerful engine on land, the beams of iron, the blocks of stone, the deep buttresses, and the powerful walls which form its bed, on which it is adjusted at once with the greatest accuracy and power, and which it nevertheless causes to quiver and tremble by its giant strokes, will readily understand the incredulity with which the first projectors of steam navigation were regarded.

The earliest application of the steam-engine was to the pumping of water. We find that when it was first used to the effect of making machinery revolve, the great lever of the pumping engine was retained. So was it in the application of the steam-engine to navigation; and the marine steam-engine most generally used at the present day, both here and in America, is called the beam-engine, or lever engine.

The first of the following diagrams represents the beam engine, or lever engine, as used on land to turn round machinery; the second represents the lever engine, as used in America to give revolution to the paddle wheels of a steam boat; and the third represents the lever engine of British steam vessels.

Fig. 1.

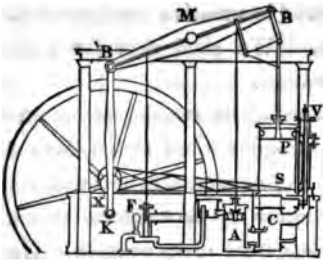


Fig. 2.

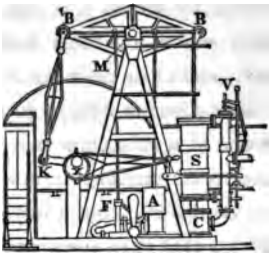
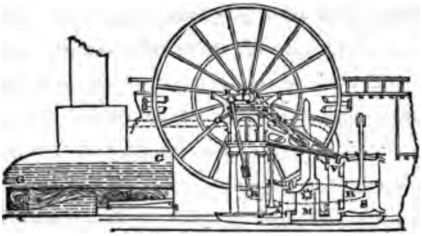


Fig. 3.



In all of these figures, S represents the place of the steam-cylinder, in which, by the alternate action of the steam on opposite sides of the piston P, that and the piston-rod P B are forced alternately to the top and bottom of the cylinder; and so the end of the lever or great beam B B is carried up and down around the centre M, carrying with it the connecting rod K B′, by whose reciprocation the crank-pin K, of the crank radius K X, is carried round on the great revolving shaft X, which, in the case of the marine engine, is the axis of the paddle wheel, and in the case of the stationary engine, is the axis only of the fly-wheel. V is the place of the valves by which steam is admitted from the boiler into the cylinder, and, after having done its duty, is educted into the condenser C, where, by a jet of cold water constantly playing, it is immediately condensed into water of the seventeen-hundredth part of its bulk, and so leaves the cylinder empty, *i. e.* nearly a perfect vacuum; and as this condensing receptacle would soon, by the jet of cold water flowing into it, and the accumulation of condensed-steam, be filled with water and its evolved gases, the air and water are pumped out at each stroke of the engine by the air-pump A, worked from the lever or working beam B B, and so the vacuum is kept perfect and the condenser effective. The feed-pump F replenishes the boiler G with some of the water extracted from the condenser, at a temperature of about 90°, and so supplies the deficiency caused by the continual evaporation of the water, at the rate of 6 gallons for each horse power every hour.

The differences between the arrangements of the marine steam-engine used in Great Britain, and the land steam-engine, are chiefly these: the lever or great beam, which, in the land engine, is above the top of the engine, and which in large engines is generally composed of a pair of thin deep beams of cast iron, united side by side into one; this single beam is brought down in the marine engine to the bottom of the engine, or rather one-half of the great beam is placed on either side of the cylinder, the two being connected together from the opposite sides of the engine, so as to act simultaneously as a single lever. This form of engine, sometimes applied to other purposes as well as to navigation, is called, from this disposition of the working beam, the side lever engine.

Another peculiarity in the marine engine, sometimes however adopted in land engines, is the place and arrangement of the condenser C, which, instead of being placed in a cistern of water, is set immediately on the centre of the engine, the condensation being wholly effected by the play of the jet of water in the interior of the condenser, without surrounding its external surface with cold water, as in the stationary engine. When thus placed, the condenser has also the advantage of giving support to the main centre of the engine, around which the levers move in giving revolution to the paddle wheels.

Before proceeding further with this article, the reader is requested to make himself familiar with the parts and arrangements of the engine already described, by referring to the plates of the marine engines given at the end, and to the descriptions of them.

It will be observed that the air-pump A is generally placed on the side of the engine furthest from the cylinder. This arrangement is convenient in point of room, and keeps the moving parts of the engine itself more perfectly in equilibrio.

Beside the air-pump is generally placed the feed pump, designed to force water out of the air-pump or discharge-pipe into the boiler. This is the general disposition of parts, which the reader will easily be able to recognise in the plates given with this article.

Although the lever engine is the form most commonly employed for marine purposes, it is by no means the only form. Very many attempts have been made to obtain engines more compact and of less weight and bulk than the lever engine. These are distinguished from the lever engines by the names vertical engines, steeple engines, and engines of direct connexion. It is still doubtful whether any of them, except in very peculiar circumstances, are practically to be preferred to the lever engine; on the contrary, objections of a serious nature are alleged against them.

We have already seen that the first steam boat, the Comet of Mr Bell, had a vertical engine. It was remarked of this vessel that the strain of the engine on the vessel was very small; but this has been attributed to the low proportion of power to the tonnage of the vessel.

Fig. 4.

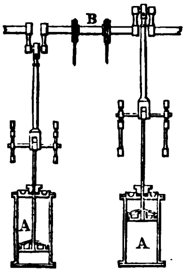
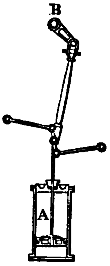


Fig. 5.



The first steam vessel whose engines we had the pleasure of seeing, had a pair of vertical engines, made by Gutzmer of Leith; the paddle-shaft B being directly over the axis of the cylinders A, as in figs. 4. and 5.

Modifications of this plan of direct or immediate connexion have been recently tried on a larger scale; but the method has the disadvantages of admitting only a short stroke and a short connecting rod, and requires that the height of the axis above the bottom of the cylinder should be at least three times the length of the stroke. Thus, one of the extremes, too short a connecting rod, too short a stroke, or a paddle axis too high above the floor of the vessel, is incurred.

To obtain the same object without incurring those evils, many descriptions of engine have been contrived. The following admits of placing the paddle axis at little more than double the height of the stroke of the engine, and gives a connecting rod of 1½ or 2 times the stroke. The piston-rod P is inserted into a cross-head *d d*, to the extremities of which two vertical rods *d e*, *d e*, are attached. With the lower extremities of these rods the side-rods *g f*, *g f*, are connected; the upper ends of these side-rods are attached to the cross-head *g g*, to the centre of which the crank rod is attached.

Fig. 6.

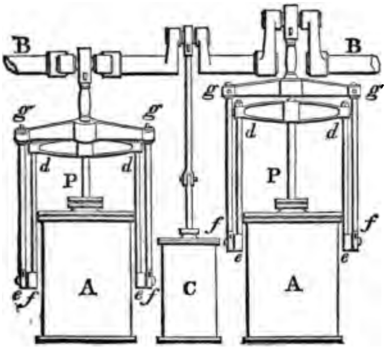
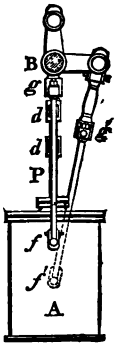


Fig. 7.



This species of engine has the great disadvantages of a multiplicity of shafts, bearings, and cranks. It was afterwards simplified by Mr David Napier in the manner represented in the following figures; viz. by uniting into one forked cross-head each cross-head with its side rods.

Fig. 8.

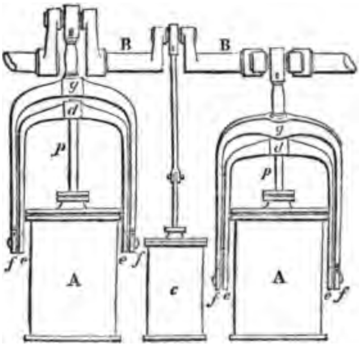
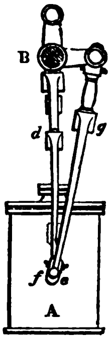


Fig. 9.



Even thus, however, limits are placed on the length of stroke and height of shaft, so as to give rise to inconvenience in many circumstances. To remedy these evils, Mr Napier appears to have invented the following class of engines, to which the cant term of steeple-engines appears to be sufficiently appropriate. In the steeple-engine the piston-rod is made forked or divaricated, so as, passing round the shaft, to rise above it to a considerable height, from which again descends the connecting rod to the crank. The following example is that of the engine of a vessel named the Clyde, the first of the kind we ever saw:—

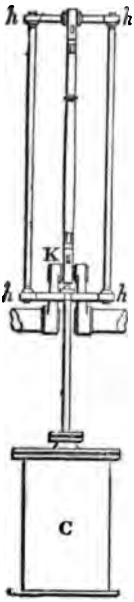


Fig. 10.

Fig. 11.

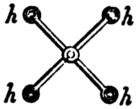
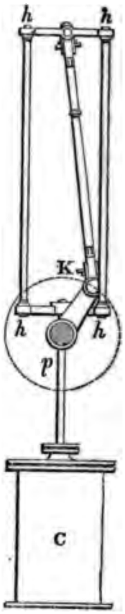


Fig. 12.



The top of the piston-rod carries a quadripartite cross-head *h h*, on each end of which stands a pillar *h h*; these four pillars again unite in another quadruple cross-head, sustained upright by a vertical guide; and it is from this summit that a connecting rod descends to the crank K. We believe that this principle of continuing the piston-rod round the axis by a forked frame was first devised, at the end of the last century, by Trevithic, the famous high-pressure engineer, and by him applied to steam carriages. It is drawn in his patent specifications.

After passing through a great variety of phases, the steeple-engine appears to have settled down into the two following shapes. In figs. 14 and 15, the piston-rod is seen united to a triangular frame, from the apex of which the connecting rod descends to the crank. In fig. 16, this frame is shown to be square, and fig. 13 is the side view of both varieties.

Fig. 13.

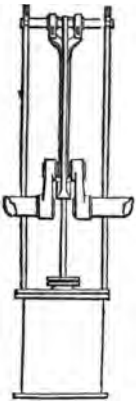


Fig. 14.

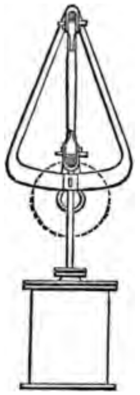


Fig. 15.

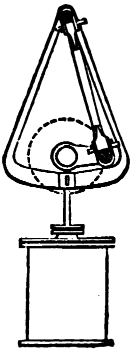
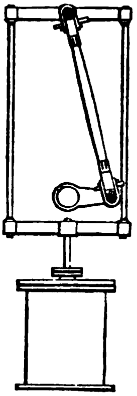


Fig. 16.



Another method of accomplishing the direct connection without encumbering the deck, has twice been patented: in the last instance by Mr Humphreys. It may be called the trunk-engine. The axis is placed at the height of half the stroke, or more, above the cylinder, and a connecting rod unites immediately the crank pin with the centre of the piston. In this way the connecting rod, passing through the top of the cylinder, would allow the steam to escape but for a large trunk or casing with which it is surrounded, and which, passing through a chasm of large area

Fig. 17.

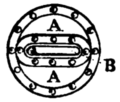
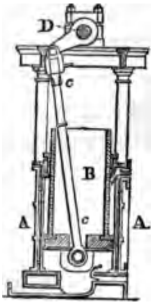


Fig. 18.



conceived to be steam-tight, rises and falls with the piston to which it is attached. In fig. 17, A A is the cylinder: to its piston is attached a trunk B, which works through a stuffing-box in the cylinder cover; to the piston the connecting rod *c c* is attached. Fig. 18 represents the top of the cylinder A A, with its stuffing-box and the trunk B.

For a like purpose, oscillating cylinders have been used with some measure of success. Rotatory engines have been unsuccessfully tried. The reader may now examine the vertical engines in the plates.

In short, it does not appear that any vessel, either on a large or small scale, constructed with an engine different from the ordinary side lever engine, has been found to be practically superior to it; and therefore we shall for the future speak of the lever-engine of the ordinary construction, when we treat of the marine steam-engine, unless when another species is expressly mentioned. The lever-engine possesses three advantages of an important nature:—first, its parts are nearly in equilibrio; secondly, its basis embraces a large part of the vessel's bottom for strength; thirdly, the lever presents great facility for working its appendages.

*The Cylinder of the Marine Steam-Engine.*—The cylinder of the steam-engine being that portion of its apparatus, by means of which the elastic force of the steam is directly applied to the mechanical arrangements by which the force of the machine is developed, is therefore the principal member of the engine, on the size of which its power and the dimensions of the other parts depend.

It is according to the dimensions of the cylinder that an engine receives its denomination, and is bought or sold. An engine is called a 10, 20, 50, or 100 horse power engine, according to the number of inches in the diameter of the cylinder. It is not to be expected, however, that every steam-engine will develope the power of a given number of horses, simply because it has a cylinder of a given number of inches. This depends equally on the proper proportion, construction, and condition of all the other parts, without which the engine will be incapable of doing its proper duty. The engines of some makers will develope double the power of those made by inferior engineers, even although in name and dimensions identical. Hence, the dimension of cylinder is taken according to a rule somewhat arbitrary, of the value both dynamical and pecuniary of the engine under the term nominal power; and the actual efficiency of the engine under given circumstances, is called the real or effective power. Hence an ambiguity is incurred in speaking of the relative powers of engines, when it is not determined whether the real or nominal power is referred to. An engine of 100 horse power, which ought to be capable of giving out an effective power of 100 horses, may, from bad workmanship, bad arrangements, or modified circumstances, only give out the real power of 50 horses; and an engine of the same dimension of cylinder, and of the same nominal power, but of better construction, may give out, and frequently does give out, real and effective power equal to that of 150 horses. Real or effective power, and nominal or mercantile power, are seldom identical, and should always be distinguished from each other.

Even the nominal or mercantile standard of power is not so perfectly invariable as may be desired. It varies a few inches according to the practice or policy of the engineer, who is frequently called upon to give an inch or two more in his mercantile dimensions, than the strict letter of his agreement might demand. Another cause of variation is this, that some engineers will prefer to sell a larger actual dimension under the name of a less number of horse power, that their engines of a given nominal power may apparently do more work than those of other people. It is a third cause of variation, that some engine makers give more than the actual dimension belonging to the power, in order that, under even the most unfavourable circumstances, the possessors of the engine may derive from it more than the full measure of the actual effective power which they require.

The following table has been constructed from a comparison of the practice of the most eminent marine steam-engine makers, with the principles of their construction. But under the dimensions given, the engines of best construction will give out from one-fourth to one-third more than their nominal power. We know, for example, that a cylinder of 74 inches diameter has been constructed under the designation of 200 horses, whereas its proper nominal power is above 225 horses, and its actual effective power, as given out in the ship, was more than 300 horses. The contraction H.P. is generally used instead of the words horse power.

*Table of the Dimensions of the Cylinder of a Marine Steam-Engine of given Horse power.*

| Nominal Power. | Dimensions of Cylinder. | |
|---|---|---|
| | Diameter (within.) | Length of Stroke. |
| 10 H.P. | 20 Inches. | 2 Feet 0 In. |
| 15 „ | 24 „ | 2 „ 2 „ |
| 20 „ | 27 „ | 2 „ 6 „ |
| 25 „ | 30 „ | 2 „ 10 „ |
| 30 „ | 32 „ | 3 „ 2 „ |
| 35 „ | 34 „ | 3 „ 3 „ |
| 40 „ | 36 „ | 3 „ 6 „ |
| 45 „ | 38 „ | 3 „ 9 „ |
| 50 „ | 40 „ | 4 „ 0 „ |
| 60 „ | 43 „ | 4 „ 3 „ |
| 70 „ | 46 „ | 4 „ 6 „ |
| 80 „ | 49 „ | 4 „ 9 „ |
| 90 „ | 52 „ | 5 „ 0 „ |
| 100 „ | 55 „ | 5 „ 6 „ |
| 110 „ | 57 „ | 5 „ 6 „ |
| 115 „ | 57 „ | 5 „ 9 „ |
| 125 „ | 59 „ | 6 „ 0 „ |
| 130 „ | 60 „ | 6 „ 0 „ |
| 150 „ | 62 „ | 6 „ 3 „ |
| 165 „ | 65 „ | 6 „ 6 „ |
| 175 „ | 66 „ | 6 „ 6 „ |
| 200 „ | 70 „ | 7 „ 0 „ |
| 225 „ | 73 „ | 7 „ 3 „ |
| 250 „ | 76 „ | 7 „ 6 „ |
| 275 „ | 79 „ | 7 „ 9 „ |
| 300 „ | 82 „ | 8 „ 0 „ |
| 350 „ | 87 „ | 8 „ 6 „ |
| 400 „ | 92 „ | 9 „ 2 „ |
| 500 „ | 100 „ | 10 „ 0 „ |

This table shows that the power of the steam-engine increases more rapidly than the area of the cylinder or the square of the diameter. By the rule of the square of the diameter, the power of an engine of 74 inches would be about 200 instead of about 225; and 100 inches diameter would give only 333 horse power; but the same rule would give too small a diameter for the lower powers. We believe that engines of the dimensions of this table will all work to more than their nominal power.

The best proportion between the diameter of the cylinder and the length of the stroke, has been the subject of much dispute, and of opposite practice. In America, a diameter of 40 inches is sometimes combined with a stroke of 10 or 11 feet, being more than double the length given in this country. On the Clyde, we have seen the opposite extreme, a diameter of 60 inches with a stroke of only 4 feet. For sea-going ships, the proportions we have given are the most convenient. In deviating from this proportion, a longer stroke will be preferable to a shorter; and with the necessary alterations required for high velocities of piston, a longer stroke working the steam expansively is likely to be attended with many advantages.

By means of a long stroke or great velocity of piston, considerable advantages are gained. The pressure upon the journals and working parts of the engine, and the consequent strain, is lessened in proportion to a given power. All the parts of the engine might be lighter than with a shorter stroke and a greater diameter of cylinder. A short stroke has however this advantage, that with a given length of lever and connecting rod, the angles of oblique pressure are smaller, and the intervals of time between maximum and minimum pressure are shorter. There are other peculiarities of smaller importance. On the whole, a longer stroke than that of the present British engine, as given in the table, is to be reckoned considerably preferable to a shorter one.

The velocity of the piston in the cylinder of a steam-engine is generally reckoned in this country at 220 feet a-minute, and all the arrangements of the engine and its work are made on that principle. We can find no better reason for this than that a horse going at that speed, viz. two miles an hour, can draw 150 lbs. eight hours a-day, all the year round. Tredgold finds it to be a law of nature. It is strange how much this arbitrary dogma, transmitted without question, has retarded the improvement of steam navigation. It is a rule as universal in its acceptation as it is groundless and injurious. With large condensers, and large ports and valves, double the speed may be employed with great advantage.

*The Condenser and Air-Pump.*—The condenser is the most wonderful part of the marine-engine, as indeed of the ordinary steam-engine. It is here that the whole process carried on in the boiler in so great bulk, and at so much expense, is instantly reversed, and all its laborious effects at once, as it were, annihilated. It is the instantaneousness of condensation that is its virtue: without this the whole of its virtue in the steam-engine is lost. Suppose a condenser capable of condensing the steam as fast as it is generated by the boiler, and given off in the cylinder, and no faster, what would be the consequence? The power of the engine would cease, the elastic force of the steam above the atmosphere would alone act, the steam being only condensed as the piston carried it out of the cylinder; the engine would become nothing else in power but a high-pressure engine, whose steam is merely condensed before going out into the atmosphere. It is by forming a perfect vacuum in the cylinder on the moment when the steam is about to enter on the opposite side, that the full power of the steam can alone be obtained in useful effect. A perfect condenser must, therefore, have much greater capability than that of merely condensing the steam as fast as the boiler is capable of evacuating it, or the engine of passing it through.

We have insisted the more strongly on this point, inasmuch as it is here principally that power is to be gained at smallest expense. Many other modes of condensation have been tried besides condensation by jet, and without effect. Newcomen tried to condense by cold water outside his condenser; so did Savary, so did Watt, so did Cartwright, so did Napier on the Clyde, so did Stevens of Hoboken in America, so did Trevithic, Symington, Mills, and many others; but without success: for though they all succeeded so far as, by having cold water on the outside of the vessels, to condense the steam in the inside, yet this condensation by contact, however perfect in quantity, has always been slower in time than condensation by jet, and has consequently failed in developing the full power of the engine. In this list we have not mentioned the name of the ingenious and enterprising Mr Hall of Basford, as he still continues to persevere against the difficulty of introducing successfully into use the system which has baffled the efforts of his predecessors; and perhaps his attempt may be attended with a higher degree of success than theirs.

It appears difficult to assign a volume to the condenser which shall give it most efficiency. We have seen efficient condensers from one fourth of the volume of the cylinder up to its full size. One-half the volume of the cylinder appears to be a size sufficiently convenient and effective.

The proper distribution of the water forming the jet, throughout the whole volume of the condenser, seems the most important point of efficacy in the condenser. Some engineers accomplish this by allowing the water to rise from the bottom of the condenser in a jet which striking the top, falls down in a shower, filling the whole condenser; others make this shower radiate in all directions from a perforated horizontal pipe; and a third most effective method is, to spread out the jet in a thin film or sheet, like a waterfall, through which the steam is compelled to pass. In marine engines, the water is permitted to flow into the condenser through a pipe in the ship's side, regulated by a cock.

Much has been said regarding the perfection of the vacuum found in the condenser of a steam-engine, especially a marine engine. It does not appear to be known that a vacuum may be too good. We hear it boasted every day by rival engineers that their engines have the best vacuum. Some boast their vacuum at 27 inches, others at 28, others at 29, some at 30, and at last an engineer appears who boasts a vacuum of 30½ inches. It is to be regretted that time and talent should be thus wasted. It is a fact of great importance, confirmed by experiment and by practice, that a vacuum may be too good, and become a loss instead of a gain. The truth is simply this, and should be known to every engineer: *If the barometer stand at 29½ inches, the standard of this country, the vacuum* IN THE CONDENSER *is* TOO GOOD *if it raise in the barometer more than* 28 *inches of mercury.* This important truth is incontrovertible, and is practically exhibited every day.

The following is a simple proof of this doctrine, divested as far as possible of a technical form, and put in the shape of an enquiry into the best state of a condenser.

Let $t =$ the caloric of water of 1°.
$c =$ the constituent caloric of water in the state of steam.
$e =$ the total force of steam in the boiler in inches of mercury;
and $x =$ the elastic force of steam at the temperature of best condensation which we seek to discover.

Then from the law which connects the elastic force of steam with temperature, as already determined in our treatise on Steam, it follows, that in the case of maximum effect, or the temperature of best condensation,

$$\frac{t}{c} = \frac{x}{e} \text{ that is } x = \frac{et}{c}$$

now $c = 1000$, and if the steam in the boiler be at 5 lbs. above the atmosphere, or if $e = 40$ inches of mercury, and $t = 1$,

$$x = \frac{40}{1000} = 0.04$$

Again, if the steam be at 7½ lbs. = 45 inches,

$$x = \frac{45}{1000} = 0.045$$

Again, if the steam be at 10 lbs. = 50 inches,

$$x = \frac{50}{1000} = 0.05$$

Hence, we find that the best elasticity or temperature in the condenser depends on the elastic force of the steam in the boiler.

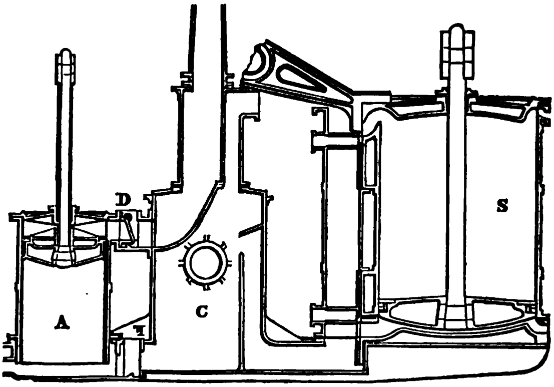
With steam of 5 lbs. in the boiler, the elasticity of maximum effect in the condenser is at 93° of Fahrenheit, and the best vacuum in the barometer is 28. With steam of 7½ lbs. in the boiler, the elasticity of maximum effect in the condenser is 95° of Fahrenheit, and the best vacuum in the barometer is 27.8. With steam of 10 lbs. in the boiler, the elasticity of maximum effect in the condenser is 97°, and the best vacuum in the barometer is 27.5. In like manner it would be found that with steam of 50 lbs. in the boiler, worked expansively, as in Cornwall, the best vacuum in the condenser would be about 26° on the barometer.

It is hoped, therefore, that engineers will not in future distress themselves, at finding the vacuum of their condenser much less perfect than the vacuum of others who have obtained 30, and 30½ inches, at so great a loss of fuel and power. To obtain a vacuum of 29½ with the weather-glass at 29.75, and steam at 7½ lbs., would be to sacrifice four horse power out of every hundred. In a day when the barometer is as low as 28½ inches, the vacuum in the condenser should indicate 26.8.

In speaking of the vacuum in the condenser, it would save much ambiguity to indicate the elasticity merely of the gas in the condenser. Thus, if the barometer stands without at 29½, and the barometer of the condenser at 28, it might be stated that the steam in the condenser stands at 1½, being the point of maximum effect; and the indication would at all times convey more precise information.

An air-pump is an appendage rendered necessary by the condenser, and especially by condensation by *jet d'eau.* Ordinary water contains about 5 per cent. of air and other gases, which become disengaged in the condenser, and must be withdrawn, to maintain the vacuum. Hence the air-pump, which is also used to withdraw the water which accumulates in the condenser. A valve between it and the condenser is called the foot valve; and a valve at the exit from the top of the air-pump is called the discharge valve. They are thus arranged: S the cylinder, C the condenser, A the air-pump, F the foot valve, and D the discharge valve.

Fig. 19.



The dimensions of the air-pump seem to vary from $\frac{1}{8}$ to $\frac{1}{5}$ of the volume of the steam cylinder. I do not know any disadvantage of importance in having a large air-pump; as, if properly constructed, the force which is required to work it will be nearly in the proportion of the elasticity of the gas which it has to remove from the condenser. To give the air-pump half the stroke of the cylinder and $\frac{1}{3}$ of the area of the cylinder, or $\frac{1}{3}$ of the stroke of the cylinder and ½ the area of the cylinder, are common proportions.

*The Valves and Valve Passages.*—The notion that because a horse can do most work at the rate of 2¼ miles an hour, or 220 feet a minute, therefore a steam-engine should also move at that rate, is a prescriptive error almost ridiculous; but from which it will nevertheless be difficult for us to escape, especially as the proportions generally in use are derived from this absurd dogma. There is no doubt that the passages and valves should simply be as large as possible, and those valves should be used which can be most enlarged with least inconvenience. Such valves we possess in the class of equilibrium valves. These valves may have an area as large as the tenth-part of the cylinder without disadvantage, and the velocity of the piston may thus be increased, and consequently the power of the engine, with great advantage, especially in steam navigation. We have the best possible means of knowing, that with proper valves and passages, the speed of the piston may very advantageously be increased to 250, 300, 400, and 500 feet a minute. The pistons of the swiftest vessels in the world move at that rate.

The kind of valve most commonly in use in steam-vessels is the long D-slide, as it is called; and next to that is the short D-slide. There are scarcely any other kinds in use in Britain. A valve called the four-port slide valve has been used to a limited extent, as have also conical valves, and equilibrium valves, or double beat valves in this country, the latter very extensively in America. The following are diagrams of the long and short D-slides.

Fig. 20.

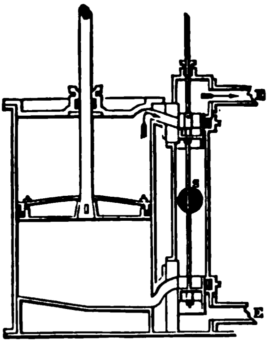
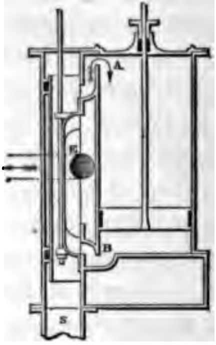


Fig. 21.



The four-port slide valve is a recent invention, having been the subject of a patent so lately as 1833. Since that time they have been used to a considerable extent in one part of Scotland. The same kind of valve was subsequently patented by another party in England, and these valves were put on board of some of her Majesty's frigates.

Fig. 22.

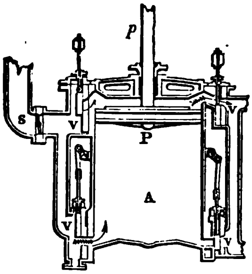
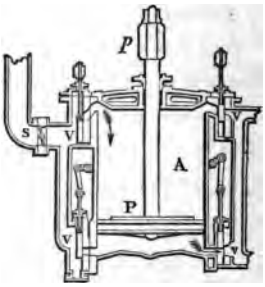


Fig. 23.



Figures 22 and 23 represent the four-port slide valve, in two positions. A the cylinder; *pp* the piston; S the steam-pipe; VVVV the slide valves. The arrows show the direction of the steam.

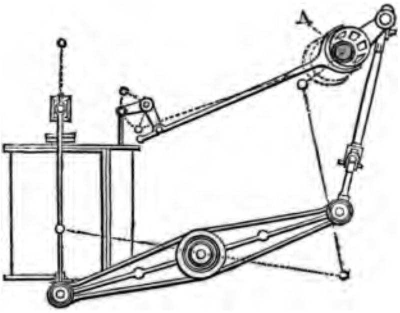
The equilibrium valve will be found fully described in our treatise on the Steam-Engine.

The size of the valves is a matter of some consequence. That the valves, passages, and ports by which the steam enters the cylinder should allow a free passage of $\frac{1}{25}$ of the area of the cylinder, is an old and pretty general rule. It is equally certain, however, that the eduction valves, ports, and passages by which the steam enters the condenser should be much larger. They have been made $\frac{1}{12}$th and $\frac{1}{10}$th of the area of the cylinder with advantage, in the case of high velocity of the piston.

*The Eccentric.*—The valves, by means of which the steam is alternately admitted to the cylinder on one side, and educted from the other side, into the condenser, are moved by the machine itself; and the very simple and beautiful automatic contrivance for that purpose is called the eccentric.

We have fully described the action of the eccentric in the treatise on the Steam-Engine. In the marine en-

Fig. 24.



gine it is placed on the axis of the paddle wheels. In fig. 24 its usual arrangement is shown, and in the Plates many examples will be found.

As the shaft A moves round, it is plain that the projection of the eccentric, first on one side of the shaft and then on the other side, will draw the eccentric rod in opposite directions; and the distance of the centre of the eccentric from the centre of the shaft, will be placed now on one side and now on another side of the axis. The motion thus produced is called the throw of the eccentric; and half the throw is equal to the eccentricity.

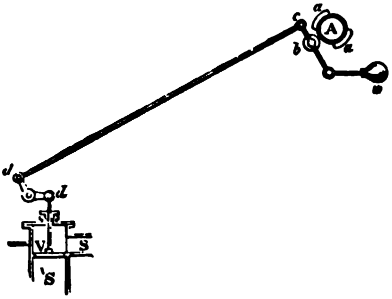
An important point in setting the valves is what is called the lead on the centres. What is the best instant of time at which to allow the steam to enter or escape from the cylinder? At first sight we should say, precisely at the instant of reversing the direction of the motion. This is not the case. Great advantage is gained by letting the steam out of the condenser before the end of the stroke. A little of the force of the steam in the cylinder may thus be sacrificed; but it is a very little, say $\frac{1}{30}$th of the stroke, and is much more than compensated by this, that the steam escaping thus early into the condenser, time is allowed for effectual condensation, and there is an excellent vacuum in the cylinder by the time when the back-stroke begins. In like manner, the steam-port may be slightly opened before the engine comes to the centre; and as there are vacuities at the top of the cylinders to be filled, and as time is wanting for the passage of the steam, this is allowed. By the same means also the steam is cut off a little before coming to the end of the stroke, which allows the engine to work expansively; and the vacuum port may in like manner be shut, as the vapour will have been perfectly condensed in the cylinder long before the end of the stroke. Much of the efficiency of an engine depends on the adjustment of the slide.

The eccentric of the marine engine is generally a loose eccentric, capable of turning the valves either so as to give the engine motion forwards or backwards. By placing the eccentric loose upon the axis, only with a projection on one side, which is carried round by a corresponding projection on the axis, it is left free, except when this check comes in contact with the projection at either end of the stroke. To effect this, it is necessary to open the valves by hand through at least one half-stroke.

*The Hand-Gear.*—The hand-gear is generally a lever or series of levers, which enables the engineer to shut and open the valves by hand before placing them in connexion with the eccentric. By this means he places the machine either in the condition to keep moving forwards or backwards. For examples see the Plates.

*The Expansive Valves.*—It is of advantage to cut off a part of the steam which would be required to fill the cylinder, so as to allow that quantity which has partly filled it to expand with its elastic force, and fill the rest of the cylinder without further supply from the boiler. The advantage of doing this, especially in long voyages has now become pretty generally known. A stop-valve V, fig. 25, is placed on the steam-pipe S S′, before it joins the casing of the common valves, which are applied as usual. The principal axis A of the engine carries a cam, with two projections *aa* proportioned in breadth to the extent of the stroke which is

Fig. 25.



cut off. On this cam rolls a small pulley *b*, pressed close by a weight *w*; and by a simple connecting rod the cam opens and shuts the valve with great velocity twice in each revolution. On this cam there may be various grades at which the steam may be cut off in the stroke of the engine. This apparatus is used in all vessels calculated for long voyages.

*The Proportion of Power to Tonnage.*—Large power or small power has always been one of the *vexatæ quæstiones* of steam navigation. The early steam-boat engines had but a small power proportioned to the tonnage of the vessels in which they were placed. The Comet had 25 tons burden and only three horse power; being about one horse power to eight tons, or a proportion of power to tonnage amounting to one-eighth.

On this subject modern practice and modern opinion seem to offer no guide. A low proportion of power and a high proportion of power have both their advocates. The East India Company have advocated and used low proportions of power to tonnage, and in this they appear to have followed the general maxims of southern engineers. The Government also appears to have adopted the same course; but without going to the same extreme. The Clyde engineers adopt the opposite maxim, and place as much power in their vessels as can be conveniently applied. There appears at the present moment to be a strong feeling in favour of a high proportion of power to tonnage. It has been found by some of the best mercantile companies, that a high proportion is not only better for expedition, but also more economical of fuel and of capital than a smaller proportion; and instances are frequent of an increase in the power of a steam vessel, producing a diminution in the consumption of fuel.

As this question is becoming every day of greater importance, it is proper to examine it carefully. In the first place, it is well known that the proportion of power must be very much increased to gain a given increase of speed. Thus, if 10 horse power propel a vessel through water five miles an hour, it will require 40 horse power to propel the same vessel ten miles an hour, or it will require a quadruple power to obtain a double speed; and, in like manner, it will require a ninefold power to triple the speed. In fact, the increased speed requires an increased power in a duplicate ratio of the increased speed; or if the speeds be as the numbers 1, 2, 3, 4, 5, 9, 10, &c., the power required to attain those speeds must be 1, 4, 9, 15, 25, 81, 100 horses; or according to the well known law of the resistance of fluids, the resistance which the water opposes to increased speed is nearly in the duplicate proportion of the speed. Thus, to increase the speed in a given proportion, the fire of the engine and the consumption of fuel, which is nearly as the power of the engine, must be increased in a very high proportion. Hence the seeming great economy of a low power of engine and a small consumption of fuel.

Thus a large power of engine occupies much of the useful space of the vessel, which might have been filled with cargo. It consumes much coal, and the speed is by no means proportioned to the expense of fuel and machinery. But this is a very limited view of the subject. If time as an element, and a very important one in the value of mercantile conveyance, be calculated, then it will in many cases be found, that high speed at any expense of fuel will compensate for that expense. This is the case to a great extent in Britain, and especially in America, where a quarter of a mile an hour between the speed of two vessels ruins the fortune of one owner, and makes the fortune of another. But it is not on the value of speed at the present day, that we proceed in this enquiry; that can at once be appreciated by the local peculiarities of a given case. We are to enquire what may be the best proportion of power to tonnage in sea-going vessels, apart from the mere price of speed in the market.

We have seen that the lowest speed in a steam vessel is the most economical, and that it requires great and expensive additions of power to gain high velocities. But in arriving at this conclusion, we have taken only the case of smooth and still water. Here it is obvious that the slowest rate and smallest power will be most economical; but it should be remembered that the great purposes of steam are generally of a different nature from the mere generation of motion through a quiescent fluid. The force of adverse winds and waves is to be opposed, stream tides and currents are to be stemmed; and it is the success of steam in conquering those obstacles, and obtaining regularity and speed in spite of them, which constitutes its superiority over wind or animal power in navigation.

Now, if we take a simple case of one of these, we shall soon find that a higher proportion of power to tonnage may be essential, not only to speed, but even to economy. Suppose a steam boat with a small proportion of power, capable of propelling the vessel at the velocity of three miles an hour through still water, to be applied to stem a current of three miles an hour, is it not plain that the vessel would make no head way, and thus a low proportion of power would burn an immense quantity of coal in doing nothing but standing still?

Let us again suppose that the same vessel, capable of steaming three miles an hour, meets with a moderately strong breeze opposed to her, such as prevents her from making any progress at all against it; then it is plain that by the continuation of this breeze, the vessel burning a continual supply of fuel would consume an indefinite quantity of coal in standing still. This extreme case of too little power, shows that there is at least one proportion of power, which is too small for economy of fuel; viz., that proportion which, being very economical of fuel in fine weather, is brought up altogether by adverse winds. In this case, the consumption of fuel is rendered indefinite, and the useful effect of fuel completely annihilated by too small a proportion of power.

As, then, we have plainly established the existence of a limit to diminution of power, in the vicinity of which it must be followed by extravagant consumption of fuel, we may now proceed to investigate the question of best proportion, or the point where the attainment of high speed is accompanied by absolute saving of fuel as compared to lower velocity. For this purpose, we merely take it for granted that the speed through the water will be nearly as the square root of the power, according to the general law of the resistance of fluids; that the resistance offered by bad weather or adverse winds has been ascertained and is determined on a particular station: that is, that it is known that on a given station a given vessel with a given power makes a voyage in adverse circumstances in, suppose, double the time of her most prosperous voyage; say her most prosperous voyage is in fourteen days, and her adverse voyage in twenty-four days, being a retarding power of ten days out of twenty-four; we take this retardation of ten days as the measure of the retarding power of adverse weather in the given circumstances. And further, let the following quantities be thus represented:—

Let $h$ be the power, $v$ the velocity, $f$ the fuel consumed, $t$ the time in good weather,
Let $h'$ be the power, $v'$ the velocity, $f'$ the fuel consumed, $t'$ the time in bad weather,
In a given vessel, on a given station.

Let $h''$ be the power, $v''$ the velocity, $f''$ the fuel consumed, $t''$ the time in good weather,
Let $h'''$ be the power, $v'''$ the velocity, $f'''$ the fuel consumed, $t'''$ the time in bad weather,
In another vessel of greater power on the same station.

Also, let $k$ represent the consumption of fuel per horse power per hour, and $s$ the length of the voyage or distance performed. Then

$$f = k\,h\,\frac{s}{v}\,. \qquad v = \text{a given quantity},$$

$$f = k\,h\,\frac{s'}{v} \qquad v' = \text{a given quantity}.$$

$$f'' = k\,h'\frac{s}{v''} \quad \text{and} \quad v'' = v\frac{h'^{\frac{1}{2}}}{h^{\frac{1}{2}}}$$

$$f''' = k\,h'\frac{s}{v'''} \qquad v''' = \left\{\left(v\frac{h'^{\frac{1}{2}}}{h^{\frac{1}{2}}}\right)^2 - v^2 + v'^2\right\}^{-\frac{1}{2}}$$

hence

$$f''' = \frac{k\,h'\,s}{v'''} = k\,h'\,s\left\{\left(\frac{h'^{\frac{1}{2}}}{h^{\frac{1}{2}}}\right)^2 - v^2 + v'^2\right\}^{-\frac{1}{2}}$$

Putting $f''' = u$, $h' = x$, and differentiating, we get

$$\frac{du}{dx} = \left(v^2\frac{h'}{h} - v^2 + v'^2\right)^{-\frac{1}{2}} v^2\frac{h'}{h}\left(v^2\frac{h'}{h} - v^2 + v'^2\right)^{-\frac{3}{2}}$$

whence by reduction, in the case of a minimum, we obtain the value

$$x = 2\,h\,\frac{v^2 - v'^2}{v^2} \ldots\ldots\ldots\ldots(\text{A.})$$

Whence we obtain the very simple rule for finding the best proportion of power to tonnage: *From the square of the velocity of any given vessel in good weather, subtract the square of the velocity of the same vessel in the worst weather, divide the difference by the square of the velocity in good weather, and the quotient, multiplied into double the horse power of the said vessel, will give the power which would propel the same vessel in the same circumstances with the smallest quantity of fuel.*

We have also from (A) $h' = 2\,h\,\dfrac{v^2 - v'^2}{v^2}$

$$(\text{B})\ v'' = \sqrt{2}\,(v^2 - v'^2)^{\frac{1}{2}}$$

$$(\text{C})\ v''' = (v^2 - v'^2)^{\frac{1}{2}}$$

$$(\text{D})\ f'' = \sqrt{2}\,\frac{k\,h\,s}{v^2}(v^2 - v'^2)^{\frac{1}{2}}$$

$$(\mathrm{E})\, f''' = \frac{2khs}{v^2}(v^2 - v'^2)^{\frac{1}{2}}$$

$$(\mathrm{F})\, t'' = \frac{s}{\sqrt{2\,(v^2 - v'^2)}}$$

$$(\mathrm{G})\, t''' = \frac{s}{\sqrt{v^2 - v'^2}}$$

It appears from the comparison of (B) with (C), that a vessel has its power in the most economical proportion to its tonnage on a given station, when its worst voyage does not exceed the time of its best in a greater proportion than $\sqrt{2}$ to 1; that is, than 14 to 10, or 7 to 5.

From (D) and (E) it further appears, that in a vessel whose power is thus proportioned, the consumption of fuel in the worst voyage will not exceed that of the best voyage in a greater proportion than 10 to 7; that is to say, for 70 tons of fuel burned in a good voyage, it will not be necessary to carry more than 100 tons, in order to provide against the worst.

Let us take as an example a Transatlantic steam ship, which has a proportion of 1 horse power to 4 tons of capacity, her unfavourable voyage between England and America being twenty-two days, and her favourable voyage fourteen days, a comparative velocity of 7 and 11, then:

$$h' = 2h\frac{v^2 - v'^2}{v^2} = 2.\ \frac{121 - 49}{121.} = 2.\ \frac{72}{121}$$

$$= \frac{12.}{10.}\ \text{nearly.}$$

Hence, the power of such a vessel should be increased in the ratio of six to five; that is to say, the engines at present capable of exerting a power of 500 horses, should have been capable of exerting a power of 600 horses, and would in this case have consumed less fuel, as well as have produced greater regularity and a higher velocity.

The following results are obtained:—

The vessel of less power burns thirty tons per day, performs the distance in fourteen days, consuming 420 tons of coals in fair weather.

The vessel of less power burns thirty tons per day, performs the distance in twenty-two days, consuming 660 tons of coals, in foul weather.

The vessel of greater power burns thirty-six tons per day, performs the distance in twelve and one-half days, consuming 450 tons of coals, in fair weather.

The vessel of greater power burns thirty-six tons per day, performs the distance in 17½ days, consuming 630 tons of coals, in foul weather; being a consumption of 30 tons less fuel, and performing the voyage in four and a half days less than the other.

It is manifest that the store of fuel carried in the vessel with less power, must on all occasions be equal to the greatest consumption of fuel, that is, to at least 660 tons, whereas 630 tons will be sufficient for the vessel of greater power; and as in all vessels for long voyages, coals carried are much more costly than the mere price of coals, or as the freight of the vessel is more costly than the fuel, coals carried are to be reckoned at least as expensive as coals burned. Moreover, as the gain in time and in capital is four one-half out of twenty-two, being about 20½ per cent, it is plain that the vessel may be calculated to perform the distance oftener in a year; because as the times of starting must always be regulated, not by the shorter but by the longest period of a voyage, seventeen one-half days in the one case, stand in the place of twenty-two days in the other.

As another example, let us take the case of a vessel calculated to stem the monsoon in the Indian seas. A vessel of 600 tons and 200 horse power, steaming in fair weather at the rate of eleven miles an hour, has been found to have her speed diminished by the monsoon to five miles an hour. What would be the best proportion of power in such circumstances?

$$h'=2\,h\,\frac{v^2-v'^2}{v^2}=2\,\frac{11^2-5^2}{11^2}=\frac{16}{10}\text{ nearly.}$$

Hence we see that the power being increased in the ratio of sixteen to ten, that is, engines of 320 horse-power being substituted for those of 200, the speed on the quick voyage would be twelve three-fourth miles an hour, instead of eleven, the speed against the monsoon increased from five to nine miles an hour, with a saving of coals amounting to forty tons out of 320; and when it is remembered that the voyage for which eighteen days would be required as continual allowance in the one case, might always be calculated on as performed in ten days in the other, the advantage is placed beyond all doubt. It appears, therefore, that for long voyages especially, great advantages in point of economy, certainty, and speed, are to be obtained by the use of vessels of a higher power than usual; and that, in a given case, the best proportion of power to tonnage may readily be determined from the rules already given.

In regard to absolute or definite proportion, it may be stated as the result of the best vessels, that the proportion of power to tonnage should not be greater than one horse power to two tons; the greater proportion holding in the smaller, and the less proportion of power in the greater vessel.

*The Proportions, Form, and Mechanical Structure of Steam Ships.*—In the treatise on ship building, the reader will find the elements of construction of ships developed and applied in a satisfactory and lucid manner. There he will also learn, that naval architecture is scarcely recognised as a science in England. The reader will therefore be prepared for the announcement that the proportions and structure of steam vessels is an enquiry which has hardly as yet systematically commenced; and it is with much hesitation that we set the example of endeavouring to eliminate from the rude mass of practical truth and practical error, some general results worthy of confidence. We may premise, that the drawing and finding the displacement, centres of gravity, and buoyancy, and the calculations of stability, &c., may be performed for steam ships by the methods, and on the principles developed in the treatise to which the reader has already been referred.

The proportions of steam vessels were originally taken from sailing vessels; the length being three or four times the breadth. Six breadths to the length is now a common proportion. The proportion of depth varies with dimension, being about one-half the breadth in vessels of 100 tons, two-thirds of the breadth in vessels of about 600 tons, and three-fourths of the breadth in vessels of 1500 tons. The qualities of a vessel depending much on its form, it is not possible to deduce a very precise rule for proportion abstracted from shape; but the following list of dimensions is deduced from a comparison of the dimensions of the best vessels, and will serve as a standard of reference for the existing state of practice. The follow ing are dimensions of flush-decked vessels without poops or forecastle. Where these exist, the depth must be diminished so as to leave the mean depth the same. Thus, in the table, a vessel of 180 feet long by thirty feet beam, has twenty feet depth; but with a half-poop she would require to be only about eighteen one-half feet deep.

*Table of Dimensions of Sea-going Steam Vessels of the best proportions, in conformity with the best practice in Britain.*

| Length between the perpendiculars. | Breadth between the paddles. | Depth, hold, and midships. | Tonnage. Old law. |
|---|---|---|---|
| 90 feet, | 16 feet, | 7 feet, | 110 tons, |
| 96 | 16½ | 7½ | 118 |
| 102 | 17 | 8 | 140 |
| 108 | 18 | 9 | 168 |
| 114 | 19 | 10 | 197 |
| 120 | 20 | 11 | 230 |
| 126 | 21 | 12 | 266 |
| 132 | 22 | 13 | 306 |
| 138 | 23 | 14 | 350 |
| 144 | 24 | 15 | 397 |
| 150 | 25 | 16 | 450 |
| 156 | 26 | 17 | 505 |
| 162 | 27 | 18 | 565 |
| 168 | 28 | 19 | 630 |
| 174 | 29 | 20 | 700 |
| 180 | 30 | 21 | 776 |
| 186 | 31 | 22 | 856 |
| 192 | 32 | 23 | 941 |
| 200 | 33 | 24 | 1044 |
| 205 | 34 | 25 | 1136 |
| 210 | 35 | 26 | 1231 |
| 216 | 36 | 27 | 1240 |
| 222 | 37 | 28 | 1455 |
| 228 | 38 | 29 | 1576 |
| 235 | 39 | 30 | 1712 |
| 240 | 40 | 30 | 1838 |
| 250 | 40 | 30 | 1923 |
| 300 | 50 | 40 | 3590 |

The form of the ship, of course, affects very materially its qualities, and the choice of proportions to produce those qualities. The dimensions in this table apply to vessels of fine proportions, having a fine entrance and run, and a side nearly upright. If however the area of the load-water line be very large, the vessel will be uneasy even with these extreme dimensions; and in such a case the beam in the table is rather excessive, while the height might probably be augmented without inconvenience. Again, if the midship section of the vessel be very square, or merely rectangular, these dimensions will suffice. If however the bilges be round, and the sides slope outwards, more breadth may be usefully employed, so as to leave the breadth at the load-water line nearly equal to, or rather greater than, the beam given in the table.

River steam vessels are, in this country, and especially on the Thames, made of great length in proportion to beam. Some of the swiftest river boats have their length equal to seven, eight, nine, and even ten times their beam, with advantage. In America they often have twelve times more length than breadth.

*The Form of Steam Vessels.*—To determine the best form of a steam-ship may appear to be a much simpler case of the great problem of naval construction, than the formation of a sailing vessel. The principal desideratum in a steam-ship being the power of going fast through the water in the single direction of the propelling power, this case of the problem appears to approach much more closely to the construction of a solid that shall receive the least resistance in passing through the water, than to the case of the sailing vessel, which has to work with a propelling power which is generally in some other direction than that in which the vessel is designed to make way. In this point of view, the problem of the steam ship is really a simpler case of the general problem than that of the sailing vessel. If, however, the steam ship is also to be a good sea boat, and to work on some occasions under canvass alone, as well as under steam alone at other times, the problem at once assumes an aspect more complex than that of either problem taken by itself.

There is, however, a single fact which is important, as it very much simplifies the subject. Vessels built expressly for the purpose of steaming, and adapted for that purpose in the best possible way, have been found, when under canvass, to equal the fastest ships in sailing qualities. Their great length and fine ends prevent them from falling to leeward; their fast formation adapts them for going through the water; their boilers and machinery form a well placed and well distributed ballast; their fine ends and flaring bows render them lively as sea boats; and the small amount of their midship section, and small resistance, give them great speed under comparatively little canvass. This practical fact, that a vessel formed exclusively for steaming, and adapted for that alone, in the best possible manner, is found to be a good and fast ship under canvass, greatly facilitates the enquiry concerning the best form of a steam ship. To this we now add another confirmatory fact, that the fastest schooners, cutters, smugglers, yachts, and slavers, approach more nearly to the form of the best steamers than any other class of sailing vessels. The problem of the best form of a steam-ship becomes thus not only simpler, but doubly interesting, from the reflex influence it may be expected to produce on sailing ships.

It is difficult, without going into minute technical details, to explain the peculiarities in the shape of the best steam ships. The present state of practice shows that systems perfectly opposite are adopted by different builders. It is at all times difficult to convert into verbal statistics forms so delicate and complex as the surfaces of double curvature formed by the bottom of a ship; but the following considerations of a general nature may probably be intelligible.

In the formation of steam-ships, it has been stated that there are opposite schools. One adopts and advocates a sharp bottom, a great rise of floor, great beam, extensive bearings on the surface, round sides, round water-lines, adopting altogether the formation of a full, capacious, stable, sea-going ship, only employing such dimensions and proportions as are given in the table of dimensions already produced. Another school adopts a flat bottom, long floor, more angular bilge, upright sides, straight entrance, clean run, sharp ends, comparatively small moment of stability, formed with the idea of going directly through the water in all weathers with the least proportion of resistance, and the smallest change of position. A third school, of recent origin, adopts the hollow wave lines and new formation, of which the principles have been established by the writer of this article The fastest steam vessels of the present day are built on this principle.

The question of form may be taken up under several heads.

*The Transverse Section, or Midships.*—The simplest and one of the earliest sections of a steam-vessel is the rectangle, fig. 26. the bottom being flat, the sides vertical, and the bilges almost angular. This form is rendered necessary when the breadth of the vessel over the paddles is to be rendered as small as possible. But this form, although it gives the greatest capacity when the breadth and depth of water are limited, is at once weak at the bilges, liable to crankness, and uneasy at sea. To remedy these evils, the bilges have been rounded, and the floor sharpened, in order to give more easy lines on the bottom, and an easier bilge, as in fig. 27.

Fig. 26.

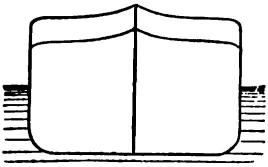
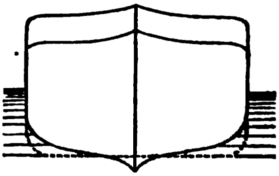
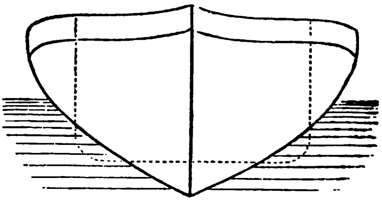


Fig. 27.



And again, this method has been carried to an extreme, or with the intention of producing the best possible sea boat, by making the floor very sharp, and the sides extremely round, thus:

Fig. 28.



But such boats are both unstable at sea, and pitch most violently. The next modes of construction have had for their object to produce the greatest capacity with the least material, and least surface of adhesion to the water. For this purpose semicircular and elliptical bottoms have been tried, thus:

Fig. 29.

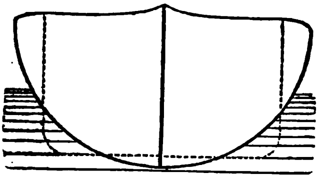
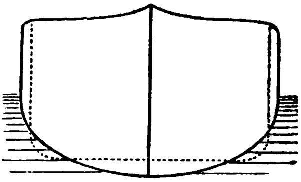


Fig. 30.



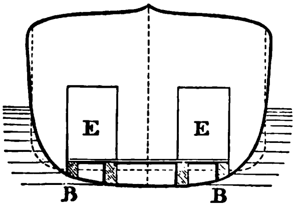
But both of these, and especially the former, although well suited for fast steamers, have a great tendency to oscillate continually, and roll with great latitude at sea.

It appears from experience, that there is great difficulty in determining that section of vessel best suited to a steam-vessel. The rectangular figure first given is, as we have said, at once weak, and crank, and uneasy. The sharpening of the bottom, as in the figures which follow it, removes the engines up from the floor, and effectively diminishes the height of the engine-room, as well as renders the vessel crank, by raising the centre of weight, and of the engines, &c., too high; and if, to counteract this evil, the beam at the surface of the water be increased as in the third section, the vessel is rendered laborious, uneasy, and ineffective at sea by the excessive beam. Again, in the round bilges the vessel swings like a pendulum, and it seems as if her oscillating would never stop. From the multitude of practical experiments which have come under our notice, we are led to the following conclusions.

1. That the existence of a fixed mass in the shape of engine and boilers, renders the usual mode of deter-

mining the midship section of a ship inapplicable to steam-ships; and that the form must be determined with immediate reference to these. 2. That the engines of a vessel of 300 horse power occupy a space of about ⅔ of the beam of a ship, which necessarily is perfectly flat; and that the engine can only be firmly connected with this floor of the ship by being placed as directly in contact with it as possible; and further, that the weight of the said engine must be placed as low as possible, on account of the place of the paddle wheel; all of which desiderata can only be obtained by making the floor of the vessel parallel to the bottom of the engine. Hence the bottom of the ship should be nearly flat across about ⅔ of her beam, thus:—B to B, fig. 31, nearly flat, E E the engines. 3. That no displacement is desirable on each side of the engines beyond what is required to give an easy turn to the bilge; for it is found, as indeed it should be expected, that all displacement on each side of the engines, at the lower part of the bilge, being vacant space, or very inefficient stowage-room, is not only wasted, but tends to impair the stability and sea-worthiness of the vessel; and, furthe[illegible] the engines being placed low, a species of stability of the most valuable nature is obtained. 4. That there are two ways of obtaining stability; one by having the weight of engines and boilers as low as possible, which is obtained by the means already described, and by depth in the water; the other by considerable beam. Now,

Fig. 31.



beam in excess is one of the worst features of a steam vessel. It produces a rolling oscillation, when the wind is in any degree on the beam, which impairs exceedingly the action of the paddles; it gives a species of roll, which is at the same time most distressing to passengers, and most injurious to the ship. All these bad effects are diminished, and can alone be corrected, by obtaining stability as far as possible from depth of the centre of weight rather than beam, according to the midship section already given.

*The Water Lines.* — Opinions on the subject of water lines, or on the degree and manner of fulness or fineness which the ends of a vessel should possess in reference to the middle, are as various as the deviations which one may conceive possible from any given shape. When with these we combine the differences of opinion concerning midship sections, which differences must also affect very materially the form of water line, we get into a labyrinth of difficulties, in the intricacies of which the good qualities of a steam ship are so often lost.

Full round ends, convex outwardly at the bow, full above at the stern, and fine enough below to steer well, so rendering the form as like as possible to an American cotton ship, with a long straight narrow body in the middle; such a form has been introduced for steam vessels, in the hope that the vessels, by having a small midship section and great buoyancy, might be easily propelled through the water. Even when they are made seven times as long as broad, we have seen vessels of this class turn out failures. They have, in the first place, been crank, in the second place wet, in the third place slow, and in the fourth place weak; for, by having too much bearing at the ends, and too little where the chief weight is to be supported, viz. in the middle, they have invariably bent down in the middle, and risen up at the ends.

Full round ends, combined with a full round midship section, are a modification from which much has been expected, as forming a ship of large capacity. This has been one of the worst and most extensive errors perpetrated in the construction of large steam ships. The great breadth along the whole water line, arising from the full lines, gives an excess of superficial stability, which, with a cross sea, causes the vessel to roll violently, with an extent and abruptness of motion which the round form of the section has no tendency to prevent or retard. Then the full ends of the vessel prevent her speed through the water, and increase her motion in a heavy sea, by increasing to excess her longitudinal stability. In the next place, if the ends of the ship be used for stowage, it is plain that the great mass of matter at the two ends must render the ship laboursome, or the reverse of lively, according to the nautical phrase; and the ship will less readily obey the helm. Such are some of the evils which, in many instances, and those especially in steam ships of the largest class, have been seen to result, and which necessarily must result, from the full and round-bodied vessel used in steam navigation.

These are not all the evils of the full form. The stowage of such vessels is by no means effective in proportion to the weight, capacity, and displacement of the ship. In the first place, by giving much space on both sides of the engine room, a very inferior species of stowage is obtained to that which results from additional length of hold. Next, the stowage room in the end of the ship, for which so much speed is sacrificed, cannot be made effective without rendering the ship unseaworthy and unmanageable; for it is notorious, that in order to rectify the erroneous fulness for which so much is sacrificed, the ends of the ship are bulkheaded off to obtain the valuable quality of liveliness. First, then, fulness is obtained at a sacrifice of speed and seaworthiness for some supposed advantage in capacity, &c.; then, that very capacity is rendered ineffectual by the injudicious mode of its application.

An opposite school from this recommends the long straight centre body of a ship, with rectangular sections and sharp, fine, wedgelike ends. This form possesses the advantage of small transverse sections, and gives great stowage: it is an easy sea boat, and is lively from its fine ends. The principal fault in this form of vessel is its liability to crankness—its weakness at the bilge. Many of the finest steam ships belong to this class.

The last class to which it is necessary to make a particular reference, are the steam ships recently constructed on the wave lines, or the hollow-entrance line—on the principle which the writer of this treatise, both by experiment and example, has laboured to introduce. The first vessel of this form was an experimental one of 75 feet keel, laid down in 1834. The next was a steam vessel of 100 feet keel, constructed in 1835. The next were two pleasure yachts of Mr Ashton Smith, a wealthy proprietor in Wales, whose observation on vessels had independently led him to the conclusion that hollow lines and a peculiar midship section gave the easiest and best sea steamers; and both of these vessels, of 1838-39, though merely approximations to the true wave lines, were remarkable for their speed and other excellent qualities. The fourth vessel of this class was the Shandon steam vessel, altered from the old to the new lines, 1840, with a gain from the same engine of from two to three miles an hour in speed. This vessel is the property of Mr Robert Napier. The next and last vessel is the Flambeau, built in 1840, on the wave principle, by Mr Duncan of Greenock, with the co-operation of the present writer. This vessel, with the smallest proportion of power to tonnage, and with the smallest supply of steam, is nevertheless by far the swiftest vessel on the Clyde. The Fire King, the largest of this new class of vessels, is 660 tons, and has engines of 220 horse power. The Flambeau has only 70 horse power to 280 tons measurement. Vessels of this class have been found at sea to be both easy, stiff, dry, and lively; while they are by far the fastest vessels of their power. The speed of the Fire King, now the property of Mr Robert Napier, is fifteen miles an hour in still water. The speed of the smaller vessel, the Flambeau, with very deficient steam, is fourteen miles an hour; a velocity which, with her small proportion of steam power, is only to be attributed to her superior form, and the slight degree of resistance which she encounters from the water.

The principle on which these wave ships are constructed is, that the hollow lines forming the entrance are to correspond, as nearly as may be consistent with the form of a ship, to the form of a certain wave capable of moving with the same velocity as the vessel. The analogy between the displacement of the water by a wave of the first order, and its displacement by a vessel moving with the same velocity, being so very close as to approach to identity, rendered it probable that the same mode of displacement would be followed in both cases with the same result, viz. the production of minimum resistance. It was further to be anticipated, that as a wave, when allowed to follow the usual mode of displacing the particles of water over which it passes, presents a smooth and unbroken swelling surface, so the vessel, if of the proper shape, according to these wave-lines, would divide the water at the bow in a smooth, unbroken sheet, instead of showing the usual head of water or surge exhibited at the bow of ordinary vessels at high velocities. On the other hand, when a wave encounters a shapeless rock, or breaks on a rugged coast, it exhibits the same violent surges which are presented on the bow of vessels of the usual form. Thus, then, the analogy leads us to suppose, that the smooth, continuous, resisting displacement of a wave, would be the best method of displacement for a vessel. On submitting the question of least resistance to the elementary calculation, it appeared that the form of least resistance was very close indeed to that of the wave. The science of hydrodynamics is not, however, sufficiently matured to enable us to place implicit dependence on all the results of its calculations, unless where they are supported by actual observation; and it therefore became necessary to make the experiment.

For the purpose of determining whether this form were that of least resistance, an experimental vessel, about seventy-five feet long, was constructed on a hypothetical form of least resistance, with the wave water lines.

When this vessel was propelled at the rate of seventeen miles an hour through the water, it was found, that instead of the usual surge exhibited at the bow of other vessels, the water was parted so smoothly and quietly, that no white spray nor other symptoms of high speed and great resistance were visible, and the parted water returned peaceably to the place it had occupied previous to the transit of the boat, with only a slight translation forwards. It appeared, therefore, from the experiment, that no greater quantity of motion was communicated to the water than was necessary to permit the vessel to pass through, and with no greater velocity than the speed of the vessel demanded. It was then presumed that this form was that of least resistance; and all subsequent experiment appears to demonstrate the truth of this inference from fact, as predicted by analogy and calculation.

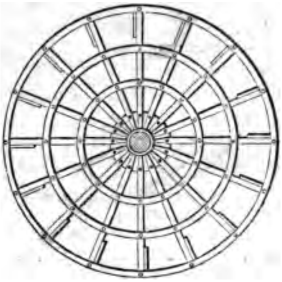
It is also worthy of remark, that this form is capable of being combined with all the good qualities of a steam ship, such as strength, dryness, easiness, as well as great speed; but as the construction of such vessels may still be deemed an experiment in progress, the writer will not occupy more space with observations on his own researches. Thus much he felt it his duty to communicate, in order to adapt this treatise to the most recent condition of steam navigation.

*The immediate Mechanism of Propulsion.* — The paddle wheel of the ordinary form (as given in the plates) seems to be the most perfect, as it is the most simple, means of propelling vessels through the water. The idea soon occurred, that as the steam-engine is calculated to turn round wheels, it is only necessary to place, on a wheel on the outside of a boat, large teeth or paddle-boards to take hold of the water, and so drive the vessel forward by simply turning the wheel. It was this plan that was adopted by Jonathan Hulls, in the first plan of a steam vessel. But there is no piece of mechanism (if we except, perhaps, the crank of the steam-engine,) which has been more despised, or which more strenuous and frequent attempts have been made to improve or supersede, than the common paddle wheel. It is remarkable, that like the crank steam-engine, the paddle wheel is almost universally employed in practice, after the fullest experiment of many diversified improvements. In fact, after experiments of all sorts of oars, propellers, paddles, chaplets, screws, &c., the common paddle wheel continues to predominate as "*the* propeller."

The numerous faults attributed to the common paddle wheel, are chiefly faults of misconception or malconstruction. It is easy to account for both.

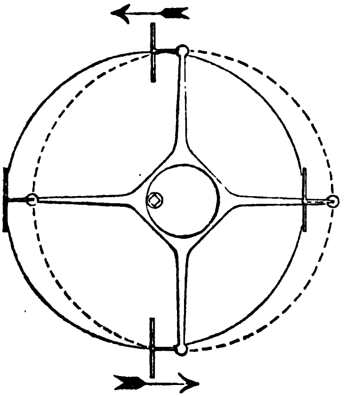
When a steam vessel is at rest in a harbour, and prevented from moving, or when in the act of setting out into motion after having been at rest, the defects of the common paddle wheel appear to be very great. The paddle boards, fig. 32., on entering the water, press obliquely down into it, tending to raise or lift the vessel up out of the water with a force which produces no useful effect. Again, when the paddle is rising out of the water behind, it seems to do little more than raise or drive the water upwards in

Fig. 32.



the form of back water. It is only, therefore, in the middle of its path that the propulsion of the paddle seems exerted in forwarding the boat, and that only for a very short time. A large part of the force of the steam-engine seems thus to be expended in raising up the vessel, and in elevating back water, and only a small portion in carrying forward the ship. But this is the case of a vessel at rest or not in rapid motion. Now it is argued from this view of the case, that the only way in which a paddle wheel could be made efficiently to perform its propelling duty, would be, by giving the paddle boards such a motion upon themselves as to keep them always in a vertical position, both on entering the water and on emerging from it. This was effected about the commencement of steam navigation by Mr Buchanan of Glasgow, in what may be designated the parallel paddle wheel.

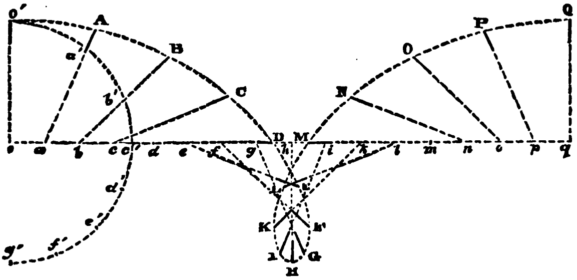
Fig. 33.



The parallel wheel, fig. 33, is constructed on this principle, "that if two equal circles be equally divided, and so placed, that the distance between two of the points of division is equal to the distance between the centres of the circles, then will all the other points of division be also equidistant, and all the straight lines joining them be parallel." By giving to each paddle board revolution on an axis, and placing an arm at right angles to it, connected by a junction-bar with an eccentric strap around the axis, the geometrical problem is mechanically constructed, and we have Buchanan's parallel paddle wheel. This wheel, with and without alterations in mechanical structure, has been invented and reproduced over and over again. It has always failed, being radically bad.

In truth, the phenomena of a paddle-wheel revolving on a steam-boat, when the vessel is in motion, differ essentially in their form and effects from the phenomena of a wheel revolving around a centre which stands still. When the vessel is only starting, or as yet moving very slowly, all the evils here mentioned do in some degree take place; but by the motion of the vessel forwards, which is the result of the revolution of the paddles, the evils complained of are at once remedied, and the paddle of a common wheel in a quick vessel is actually "feathered," according to the most dexterous toss of the practised rower. A little study of the geometrical conditions of a paddle moving forwards and in a circle at the same time, will make this plain. Let us trace for this purpose the motion of a single paddle. At the point *o*, the paddle-board O being in the position O′, the

Fig. 34.



wheel, turning on a stationary axle, would bring the board *o* successively into the positions *a'*, *b'*, *c'*, *d'*, *e'*, *f'*, *g'*, &c.; but the axle being advanced by the motion of the boat into the places *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, *i*, *k*, *l*, *m*, *n*, *o*, *p*, *q*, in the same intervals of time, and these motions being simultaneous, the paddle-board describes a path in reference to the water which is the result of both, and the successive positions of the paddle-board are *a*A, *b*B, *c*C, *d*D, *e*E, *f*F, *g*G, &c. The paths described by the boards are trachoidal curves, being of the family of the cycloid. Now, from the study of the actual motion thus performed by the paddle-board of the common wheel, it is plain, first of all, that the paddle is inserted into the water in an angular position resembling closely the entrance of an oar into the water; that it is then made to act horizontally on the water during a short interval after which it is withdrawn from the water, edgeways, in an easy and elegant manner, which the dexterous rower might envy and try to equal, but which he could hardly excel.

All this, however, takes for granted that the paddle and the boat are well proportioned and placed; otherwise all this perfection may be impaired or lost. To this exposition of the subject, it may be added, that the common paddle-wheel is in practice, as it ought to be in theory, exempt from the faults generally attributed to it; and that experiment has shown that its action presents as much perfection in operation, as its simple form and mechanical arrangements do in enabling the artist to give it durability and strength.

When the paddle-wheel is badly proportioned, badly placed, attached to a very slow or full boat, or immersed too deep in the water, its action becomes impaired or impeded. Hence much attention has been devoted to the construction of a paddle that should be more effective in these unfavourable circumstances than the common wheel; in short, to construct a paddle-wheel that should be an effective propeller, even when immersed to its axis, or wholly placed under water. This may be properly enough called the radiating paddle, as distinguished from the parallel paddle.

The radiating paddle is not constructed on the fallacious view of the subject which gave rise to the invention of the parallel paddle wheel. On the contrary, it proceeds on the hypothesis, that the actual motion of a paddle wheel on a moving ship is cycloidal; and its intention is to adapt the wheel with greater perfection to that cycloidal motion. The theorem on which it is founded is as follows. Let the circle in the following diagrams, figs. 35, 36, represent that circle in a paddle-wheel which is described by a point moving in the common cycloid, that is, where velocity in the circle is equal to the velocity of the vessel, *o* being the centre of the paddle wheel,

Fig. 35.

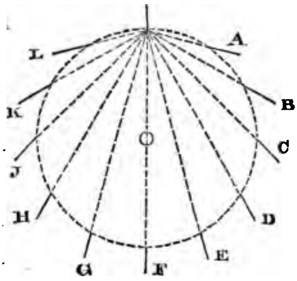
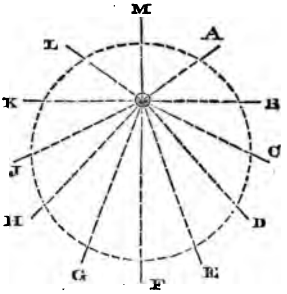


Fig. 36.



then, by the property of the cycloid, all lines drawn from the point M at the superior extremity of the vertical diameter of that circle to A, B, C, D, E, F, &c., points in its circumference, will be parallel to the cycloid of progression, or rather to its tangents, at the points of its periphery which correspond to A, B, C, D, E, &c., when in motion. If it were possible to construct this geometrical problem in a mechanical apparatus, this paddle wheel would have great efficacy even when very deeply immersed. It is, however, difficult to make this motion perfect at M. But this species of mechanism has been very beautifully combined and arranged by Morgan, Seaward, Cave, and others, whose geometrical apparatus is very beautiful. Unhappily the apparatus, even in its most perfect state, is only correct for a single velocity of vessel and of wheel: for a different velocity, the point of radiation of the paddles must be changed, or loss is at once incurred. Hence it is found that this apparatus, like the common paddle, is liable to imperfections of action, with every change of immersion and velocity. When to this there are added the complexity, friction, cost, wear and tear, liability to accident, of this moving mechanism, introduced for obtaining the partial remedy or slight amelioration of an evil which by proper arrangement is but slightly felt under the old method, it becomes manifest, that the general abandonment of the radiating paddle-wheel, and the return to the common one, has not been without sound practical reason.

The last species of paddle-wheel is that with the fixed float; in other words, the simple paddle-wheel with boards placed around its rim. Of this there are various modifications. A very simple modification is that mentioned by Mr David Stevenson, in his excellent work on the civil engineering of America. The paddle board of the usual wheel is, as it were, cut in two, one half being placed half an interval in advance of the other, as in figs. 37 and 38. This may be called the divided paddle wheel. The concussion of a paddle wheel striking the water is much lessened by this means, and the propelling force is rendered more nearly uniform. Another form of this wheel may be named the split paddle wheel, from having the paddle-board, as it were, split into two or more horizontal slips, by which the same advantage is obtained as from the divided paddle wheel. It has been proposed to place these strips in a cycloid; but no advantage results from the arrangement although the dignified name of the cycloidal paddle wheel has been applied to it. Again, it has been proposed to place the paddle boards at all sorts of angles with the axis of the wheel, both horizontally and vertically, but as yet without advantage.

Fig. 37.

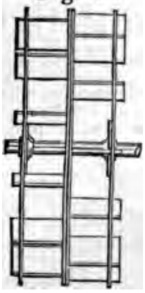


Fig. 38.

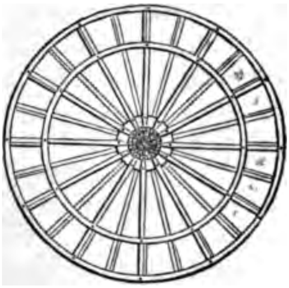
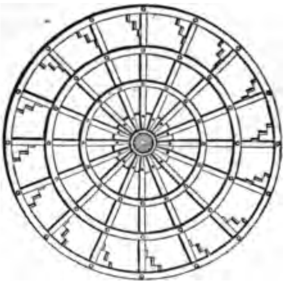


Fig. 39.



Split Paddle Wheel.

A very simple expedient tends to remove all considerable irregularity or concussion from the common paddle-wheel. It is to allow the extremity of the paddle board nearest the side of the boat, to descend from six to twelve inches deeper in the water than the outer extremity. This plan was carried into effect by the writer of this treatise on a steam vessel in 1836. The desired object was attained without any sacrifice of power or speed. For distinction we may call this the conical paddle wheel. It is shown in figs. 40, 41.

Fig. 40.

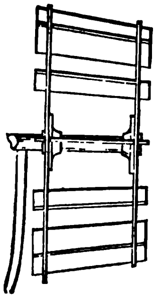
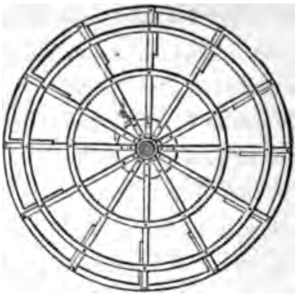


Fig. 41.



Conical Paddle Wheel.

In the three following figures we have represented the single oblique paddle wheel. Fig. 44 shows the development or stretch-out of a part of the circumference of the wheel, to exhibit more clearly the arrangement of the paddle boards.

Fig. 42.

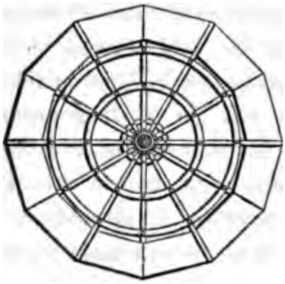


Fig. 43.

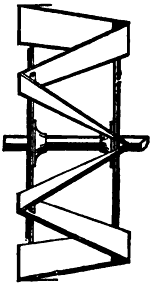
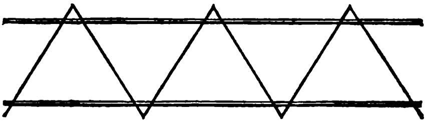


Fig. 44.



Single Oblique Paddle Wheel.

In figs. 45, 46, the double oblique paddle wheel is represented; and in figure 47 the development of a portion of its circumference is given.

Fig. 45.

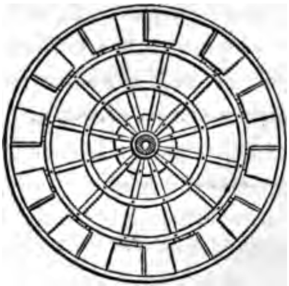


Fig. 46.

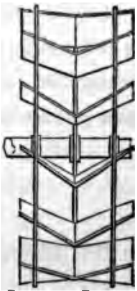
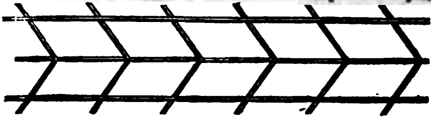


Fig. 47.



Double Oblique Paddle Wheel.

*The Reefing Paddle.*—One of the greatest improvements on paddle wheels, and one of especial importance to steam navigation, still remains to be invented. We mean such a mechanism as shall enable the steam commander to set out on a long voyage deeply laden, with a small diameter of paddle wheel; that is, with the paddle boards near to the axis, and to increase the effective diameter of the paddle, that is, to remove the paddle boards further from the axis, as the vessel proceeds on her voyage and is lightened by the consumption of coal. The invention of a durable, economical, and safe apparatus still remains to be made. In the infancy of steam navigation, Mr Buchanan of Glasgow published an account and drawing of a reefing paddle; Messrs Bolton and Watt are also in possession of a very old method of reefing paddles; the Society of Arts in Scotland offered a prize several years ago for the invention, without obtaining, out of many plans, one to be recommended for practice; and, finally, the indefatigable inventor, Mr Hall of Basford, has patented a very elegant mechanism for the same purpose. It still, however, remains to introduce and establish a perfect reefing apparatus, and the author of such a system will render the common paddle wheel a perfect propeller.

## HISTORICAL SKETCH OF STEAM LOCOMOTION.

THE history of locomotives is inseparable from that of the high-pressure engine, first hinted at by the Marquis of Worcester, and brought into practical use by Savary, who proposed it for propelling carriages.

After the magnificent improvements of James Watt, high-pressure engines were neglected for many years. With reference to locomotion, however, the next suggestion seems to have come from Dr Robison, then a student in the university of Glasgow, who proposed, in 1759, the steam-engine to Watt as a means of moving wheel carriages. Murdoch, in 1782, to whom Trevithick was a pupil, made a model of a steam carriage, which was exhibited to many persons. In 1784, Watt explains, in his patent, the manner in which, among other things, he proposes his engine to propel carriages. This method, although a curiosity at the present day, bears the full impress of his mind. The boiler was to be of wooden staves hooped together with iron like a cask; the iron furnace was to be inside the boiler and almost entirely surrounded by the water, the whole being placed on a carriage, the wheels of which were to be worked by a piston, the reciprocating motion being converted into a rotatory one by toothed wheels and a sun and planet motion. His system of wheels was a double one, their proportions differing, and by this contrivance he proposed to overcome the variable resistance to be found on the road. The cylinder was to be seven inches diameter, the number of strokes sixty per minute, and their length one foot. The carriage thus constructed was to carry two persons. Watt, however, never built it, and continued till his death an opponent of high-pressure steam.

The first person who may properly be said to have reduced the theory to practice was Richard Trevithick, who seeing that lightness and portability were indispensable in any attempt at locomotion, either on common roads or on railroads, at once adopted the high-pressure principle.

This was in 1802, when, in conjunction with Vivian, he took out a patent. The condenser, cistern, air-pump, and cold water pump were omitted and the engine thus lightened, became not only considerably cheaper, but had the power to move itself, as well as to carry a load as a wheel carriage. At first it was tried on common roads, and was exhibited before thousands of people; among other places, near Euston square, where the London and Birmingham railway company's station is now fixed.

The carriage presented a handsome appearance, having two small wheels in front by which it was guided, and two large ones behind by which it was driven. It had but one cylinder, and this, together with the boiler and fire, which were all enclosed in a case, was situated low down and in the rear of the hind axle; each driving wheel could be worked separately, or one could be reversed while the other went forward, their motion being produced by spur gear, to which was added a fly-wheel. The piston-rod outside the cylinder was double, and drove a cross piece, working in guides, on the opposite side of the cranked axle to the cylinder, and the crank of the axle revolved between the double parts of the piston rod. To this axle was attached the first of the toothed wheels; and to the axle on which were the driving wheels was attached the other, similar in size to the first, and worked by it. The steam cocks were opened and shut by a connexion with the crank axle. The force pump, by which a supply of hot water, contained in the casing which enclosed the cylinder, fire box, &c., was injected into the boiler, was also worked from it, as were the bellows to produce sufficient combustion. The specification of his patent also adverts to contrivances for increasing the adhesion of the wheels, although they are said to be in general unnecessary; and it distinctly alludes to these engines being adapted for railroads.

Some writers have assigned to Trevithick the merit of inventing the steam blast up the chimney, which may be termed the life blood of the locomotive engine. Trevithick has laurels enough, and has no need to borrow a single leaf from the crown of another. The steam blast was invented by George Stephenson, and used by him certainly prior to 1815; while in June 1815, Trevithick, so far from using the waste steam to increase the draught, took out a patent, in which, among other improvements, he included a method of urging his fire by fanners, similar to a winnowing machine.

In 1804, Trevithick took out another patent for a locomotive engine, in which he used a cylindrical boiler with flat end, since called by his name. The fire door is near the chimney, and the furnace and flue is inside the boiler, the latter recurving and having its exit at the same end at which it entered. The cylinder is immersed in the boiler, all but a portion of the upper end, which is inclosed in a socket surrounded by the steam. In his first engine, the cylinder was horizontal, in the above it was vertical; and it is in this latter that the waste steam was thrown into the chimney. It is curious that such an able man as Trevithick should not have discovered the advantage of this; for although his exit pipe was not regulated so as to produce any thing near the maximum effect, either by its position or size, yet it must inevitably have increased the draught, although it is no less certain that he afterwards abandoned its use.

This engine was worked at Merthyr Tydvil in South

Wales, on a very indifferent tram-road. The wheels were plain, and were found to have ample adhesion. It drew ten tons of bar iron, together with the necessary carriages and its water and fuel, at five miles an hour. It was not till a long time after this that any other considerable improvement took place; and an imaginary difficulty, perhaps, had no little effect in retarding the advance of locomotives: this was an idea which prevailed for some years, that adhesion between the wheels and the road was the thing wanted. There never was a greater mistake; the force of gravitation is found to be amply sufficient, and if not, adhesion can be had to an almost unlimited extent, by a galvanic action induced between the engine and the rails.

The next considerable improvement was in 1811, when a patent was taken out by Blenkinsop for the first double cylindered engine. The boiler was circular, having the fire door at one end, opening into a tube in which was the furnace. This tube ran through the the boiler, and making its exit, without any recurving, at the opposite end, was bent up to form the chimney. The cylinders were principally in the boiler; they were both vertical, eight inches in diameter, and their upper ends were outside the boiler at the top, where the eduction pipes met in a single tube, and threw the steam into the air. The piston rods, by means of cross-heads, worked the connecting rods, which came down to two cranks on each side below the boiler, placed at right angles in order to pass their centres with certainty. These cranks worked two shafts, fixed across the engine, on which were small toothed wheels working into a larger one between them. On the axis of this, and outside the framing, were the driving wheels, one of which was toothed and worked into a rack on one side of the railway: there were two pair of two plain flanged wheels, one before and one behind the driving pair, which ran on rails in the usual way. The weight of this engine was stated to be 5 tons, its consumption of water 50 gallons per hour, of coal 75lbs per hour, and it drew 94 tons on a level at 3½ miles an hour, or 15 tons up 1 in 15; its maximum speed was 10 miles an hour, and its cost £400.

The next patent was in 1812 to Messrs Chapman. Here the first mention of fanners to excite combustion occurs. The motion was to be produced by having a chain passing round a barrel fixed to the engine. The chain was to be stretched along the railroad and made fast at each end, the barrel being set in motion by spur gear. It had eight wheels, the boiler was Trevithick's; it was tried at Heaton colliery, but did not succeed; its weight was 6 tons, and it drew 54 tons up 46 feet in a mile, or about 1 in 115 at 4 miles an hour. This latter performance, however, was by an engine differing from the above; the wheels were worked by spur gear and not by the chain, and it could not start the above load without considerable slipping of the wheels, although it drew it when once in motion; hence 115 in. has been supposed the limit of adhesion with an engine weighing 6 tons; this, however, is not correct. In these old engines, the adhesion had relation to the number of wheels, which in this case was eight. In the modern ones it has reference more to the manner in which the weight is distributed, the driving wheels always having, of course, the greatest proportion. Trevithick's engines were tried by Mr Blackett of Wylam, in 1813, and were worked by the adhesion of their wheels only. This was on a tram-way.

We now come to George Stephenson in 1814, whose first effort was the construction of an engine for the Killingworth colliery. This had two vertical cylinders, partly within the boiler and partly above it. This engine worked upon what is termed the second motion, that is to say, the connecting rods worked a middle axle communicating by means of spur wheels to the main shaft, on which were the engine wheels; these were four in number, and were fixed to their axles; so the cranks, which were at right angles, turned two cogged wheels, and these gave motion to two others twice their diameter, fixed on the main axles. The cylinders were not so far apart as those in use at present, in order to give as much perpendicularity as possible to the connecting rods; the middle cranks worked within the case of the engine; the chimney was cast iron, around which was a chamber extending back to the feed pumps, for the purpose of heating the water previous to its injection into the beiler.

In order to neutralize as much as possible the shocks which this engine would meet from obstacles or inequalities on the road, as it had no springs whatever, the water barrel, which served as a tender, was fixed to the end of a lever and weighted; the other end of the lever being connected with the frame of the locomotive carriage, thus keeping up a vibratory motion on an uneven way. The boiler had one large tube in the centre, and rested on the carriage frame; but the lever apparatus was not found to compensate for the total absence of springs; and that it was inefficacious was of course soon discovered, by the machinery becoming deranged from the shocks. In fact, on this very engine the fate of locomotives may be said to have hung. It never made full steam enough to go more than about three miles an hour, and would have been condemned as useless had not Mr Stephenson at last applied to it the steam blast. This at once doubled the power of the engine, enabling her to go six miles an hour and maintain her steam. Even then this engine only ran about twelve months, and gave place at the end of that period to further improvements.

The next locomotive constructed by Mr Stephenson was that for which his first patent was obtained. This was taken out in February 1815, in conjunction with Mr Dodd, and the alteration consisted in using a crank pin outside the driving wheels; one pair of which was worked by each cylinder, the crank pins being kept at right angles by means of an endless chain working round wheels fitted with cogs to receive the links. These wheels and the chain superseded the use of spur gear, which had been found objectionable, and this engine worked well. It had a third pair of wheels between the two driving pair.

In June 1815, Trevithick took out another patent, in which he proposed fanners consisting of "flat plates or leaves," revolving in a case, which were to "produce a current of air in the manner of a winnowing machine, to blow the fire." He also, in the same patent, proposed to "place in the flue a screw or set of vanes, somewhat similar to a smoke-jack," which were to "revolve by connection with the steam-engine, for the purpose of creating an artificial draught in the chimney." Similar contrivances to these were afterwards claimed by Lord Cochrane and Mr Galloway, and also by Messrs Braithwaite and Ericson. The former contrivance—namely, fanners revolving rapidly inside a circular drum has been lately used with success as a most powerful blowing machine for iron furnaces, and other works requiring a very intense heat; yet the invention is nearly 200 years old, and at so remote a period it appeared in print with explanatory engravings. One kind of tubular boilers had long been known, and were used by Trevithick; being in this patent stated as a part of his apparatus, although he only claimed a modification of them. They were vertical, and contained water, not fire or hot air, like those of a recent construction.

The next patent was in 1816 to Messrs Stephenson and Locke, with which the improvement of Stephenson and Dodd was incorporated. This patent extended to railways, carriage wheels, and several other useful matters connected with the same subject, and, among other things, the following contrivance was introduced. The weight of the engine rested on steam-springs by means of three pair of small cylinders, fixed to the lower part of the boiler, and open to the inside of it, in which they entered for several inches. These cylinders were also open at the bottom, and a piston rod, with a solid piston, worked in them: the lower end of these piston rods, after passing through a hole in the framing of the engine, were fixed to the working cods, over the axle of the wheels; hence any oscillation in the carriage of the engine was transferred to those pistons, which, acting against the pressure of the water, or more properly speaking, of the steam, performed the office of springs; Hence the steam supported the weight of all the machinery, except that which was connected with the framing. The furnace in these engines was contained within the boiler; the door of it opening at the opposite end to the chimney, and not at the same end like Trevithick's.

In the above engines, the second motion or spur gear was also discontinued, and the endless chain used instead. They had six wheels, and worked with cranks, like the present ones. The metal, or cast-iron chimney, and heating apparatus, was also set aside. The six wheels were continued in use as long as the steam springs were applied, and when steel springs were adopted they were again reduced to four.

The opinions which were then entertained respecting the improvements that were destined, in a short period, to effect a complete revolution in all our ideas of time and space, as far as they relate to travelling, may be gathered from what Mr Galloway says in his *History of the Steam Engine.* "These locomotive engines have been long in use at Killingworth colliery, near Newcastle, and at Hilton colliery on the Wear, so that their advantages and defects have been sufficiently submitted to the test of experiment; and it appears, that notwithstanding the great exertions on the part of the inventor, Mr Stephenson, to bring them into use on the different railroads, now either constructing or in agitation, it has been the opinion of several able engineers, that they do not possess those advantages which the inventor had anticipated; indeed there cannot be a better proof of the doubt entertained regarding their utility than the fact, that it has been determined that no locomotive engine shall be used on the projected railroad between Newcastle and Carlisle, since, had their advantages been very apparent, the persons living immediately on the spot in which they are used, namely, Newcastle, would have been acquainted therewith.

"The principal objections appear to be the difficulty of surmounting even the slightest ascent, for it has been found, that a rise of only one-eighth of an inch in a yard, or of eighteen feet in a mile, retards the speed of one of these engines in a very great degree, so much so indeed, that it has been considered necessary, in some parts where they are used, to aid their ascent with their load, by fixed engines, which drag them forward by means of ropes coiling round a drum. The spring steam cylinders below the boiler were found very defective, for in the ascending stroke of the working piston, they were forced inwards by the connecting rod pulling at the wheel in turning it round and in the descending stroke the same pistons were forced as much outwards: this motion or play rendered it necessary to increase the length of the working cylinder as much as there was play in the lower ones, to avoid the danger of breaking or seriously injuring the top and bottom of the former, by the striking of the piston, when it was forced too much up or down."

Several patents were now taken out, proposing various modifications of tubular boilers, the tubes containing the water, and other contrivances, mostly adapted to steam-carriages on common roads. So late as October 1825, a new form of racked rail formed the subject of one of them; in this it was proposed to be in the middle of the railroad, which was to be composed of masonry. In 1826, Mr Robert Stephenson, senior, proposed an ingenious method of obviating the friction between the flanges of the wheels of a locomotive engine and the rails, by having a separate axletree to each wheel, so that they might revolve independently, and at different velocities. By another plan, in the same patent, he proposed to allow one end of each axletree to move in a ball and socket joint, while the other, the wheel end, instead of revolving in a circular aperture, was to have a motion up and down in a vertical slot, so as to accommodate itself to the inequalities of the rails. Mr Chapman, in 1827, took out a patent for a similar purpose.

The obstacles which Mr Stephenson encountered in his attempt to bring locomotives into general use, may be easily conceived by what took place when the Liverpool and Manchester railway drew near its completion. An enquiry was there instituted into the comparative merits of fixed and locomotive engines, and in the spring of 1829, Messrs Walker and Rastrick, engineers, were commissioned by the directors of that line to examine into both modes on the existing railways, and report on their relative advantages. After the most careful examination into all the branches of expenditure, and also the power and capabilities of the locomotive engines as they stood at that day, these gentlemen reported to the directors of the Company in the following terms:—"upon he consideration of the question in every point of view, taking the two lines of road as now forming; and having reference to economy, despatch, safety, and convenience, our opinion is, that if it be resolved to make the Liverpool and Manchester Railway complete at once, so as to accommodate the traffic as stated in your instructions, or a quantity approaching to it, the stationary reciprocating system is the best." They also stated that if it was only intended to proceed by degrees, proportioning the power of conveyance to the demand, in that case they would recommend the use of locomotive engines.

As it was absolutely necessary that the railway should be made complete at once, this opinion was tantamount to a condemnation of locomotives. Messrs Robert Stephenson and Locke, therefore, on the publication of the report in question, undertook its examination as to the correctness of the various deductions which were laid before the directors; and the different statements which they produced, arising in a great measure from improvements made by Mr Stephenson in his engines, since Messrs Walker and Rastrick formed their estimates, fortunately for the world turned the scale the right way.

From the statements of Messrs Stephenson and Locke, it appeared, that the locomotive system would cost £63,496 less than the stationary, and £16,515 less per annum in working expenses. We shall place the two results of these different estimates together, as forming a record of no ordinary interest, now the one system has so completely been established as totally superior to the other, except on very short lines.

| System. | Capital. | | Annual Expense. | | Cwt. per ton per mile. | |
|---|---|---|---|---|---|---|
| | Walker and Rastrick. | Stephenson and Locke. | Walker and Rastrick. | Stephenson and Locke. | Walker and Rastrick. | Stephenson and Locke. |
| | L. | L. | L. | L. | D. | D. |
| Locomotive engines, | 90,404 | 58,000 | 43,464 | 25,517 | 0·2786 | 0·164 |
| Stationary ditto., | 100,862 | 121,496 | 33,317 | 42,032 | 0·2135 | 0·269 |
| Locomotive system, | 10,458 | 63,496 | 10,147 | 16,515 | 0·0651 | 0·105 |
| | Less. | Less. | More. | Less. | More. | Less. |

After well considering these reports and the observations made on them by Mr Stephenson, the directors took the wisest step which they could possibly have taken; and this was, to offer a premium of £500 for the best locomotive engine, which should draw on a level plane three times its own weight at ten miles an hour, which weight was not to be more than 6 tons. The price of the engine was restricted to £550; the height of the chimney to 15 feet; the pressure on the boiler to 50 lbs. per square inch. It was to consume its own smoke; the whole weight of the engine and boiler was to be supported on springs; and, if this weight exceeded 4½ tons, the engine was to have six wheels. The premium was offered in April 1829, and the trial was to take place in October of the same year. It is from this point we may date, with the exception of the steam blast, the era of modern locomotion on railroads.

The engines entered for the competition, were as follows:

| Engine. | Maker. |
|---|---|
| Rocket | Robert Stephenson. |
| Novelty | Braithwaite and Ericson. |
| Perseverance | Burstall. |
| Sans Pareil | Hackworth. |
| Cyclopede | Brandreth. |

The latter was a horse locomotive, and was therefore not considered as entitled to run for the prize. It was tried, however, as a matter of experiment; but its speed was only about six miles an hour. After a short trial, the Perseverance was withdrawn by its proprietor. The competitors were consequently reduced to three; viz.

| | Engine weight. | | | | Drawn weight. | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | tons. | cwt. | qr. | lbs. | tons. | cwt. | qr. | lbs. | |
| Rocket | 4 | 5 | 0 | 0 | 3 | 4 | 0 | 2 | tender. |
| | | | | | 9 | 10 | 3 | 26 | two carriages. |
| | | | | | 12 | 15 | 0 | 0 | |
| Novelty | 1 | 18 | 2 | 19 | 5 | 16 | 0 | 0 | |
| Sans Pareil | 4 | 15 | 2 | 0 | 3 | 7 | 3 | 0 | ...tender. |
| | | | | | 10 | 19 | 3 | 0 | ...three carriages. |
| | | | | | 14 | 6 | 2 | 0 | |

The Novelty carried its own fuel and coke, without any tender. The ground chosen for the trial was on the Manchester side of Rainhill bridge, about nine miles from Liverpool, where the railway is on a level. The Sans Pareil being above the weight, was tried only as an experiment, and was found to draw twenty tons at fifteen miles an hour; the fuel consumed was, however, very great.

The Novelty likewise had to be withdrawn, through a series of unfortunate accidents which had no reference to the character or capabilities of the engine; and we well recollect, that it made a powerful impression on the public mind at the time. On the first day of trial, Thursday, October 6, 1829, it went twenty-eight miles an hour (without any attached load), and did one mile in seven seconds under two minutes. This performance will now appear trifling; but at the time the sensation produced was immense. Mr Nicholas Wood, who was appointed one of the judges on the occasion to award the premium of L.500, had, even after the opening of the Stockton and Darlington railway, published his opinion respecting locomotives as follows: "It is far from my wish to promulgate to the world, that the ridiculous expectations, or rather professions of the enthusiastic speculatist, will be realized, and that we shall see engines travelling at the rate of 12, 16, 18, or 20 miles an hour. Nothing could do more harm towards their adoption or general improvement, than the promulgation of such nonsense." And that the directors of the Liverpool and Manchester railroad in some measure agreed with this opinion, may be inferred from their appointing that gentleman as an umpire, and only requiring the engines to travel with three times their weight at ten miles an hour.

On the second day's trial, the Novelty drew 11 tons, 5 cwt., at 20 miles and three quarters in an hour; but unfortunately for the owners, some of the tubes gave way at the joints during the succeeding trials, and the competition was given up, thus leaving a clear course open to Mr Robert Stephenson's Rocket, the performance of which we have now to state, first premising that Robert Stephenson, (a brother of George Stephenson,) we have often heard erroneously mentioned as the individual who made the Rocket. It was made by his nephew, the engineer of the London and Birmingham Railway. Mr Robert Stephenson, sen., was not an engine maker.

The Rocket was the only engine which performed the required distance of 70 miles, with the given load, and at the stipulated speed. Without a load it went at the rate of 30 miles an hour, and when drawing three times its weight, at upwards of 24 miles an hour. It completed the first 35 miles in three hours and ten minutes, being upwards of 11 miles an hour; and after taking in a fresh supply of water, it performed the second 35 miles in 2 hours 52 minutes, being at the rate of upwards of 12 miles an hour; and this speed, it must be remembered, included all the stoppages at each end of the trial ground, which was one mile and three quarters long. One-eighth of a mile was allowed at each end for getting up the speed and stopping the train, but this advantage is not included in the above. Had the 70 miles been in one length, it is judged the Rocket would have maintained an average velocity of at least 15 miles an hour. The coke consumed was 142 lbs. in getting up the steam, and 1085 lbs. in running the 70 miles, and 579 gallons of water were used. This trial of the Rocket took place on October 8, 182[illegible]

The Rocket was constructed with four wheels not coupled: its boiler was six feet long and three feet in diameter, and contained twenty-five copper tubes, three inches in diameter, through which the heated air from the furnace passed in its way to the chimney. The furnace, which was at the after end of the engine, was two feet wide, and three feet high, and had an external casing, between which and the fire box there was a space of three inches filled with water, and communicating with the boiler. The cylinders were placed on each side of the boiler in an angular position, one end being nearly level with the top of the boiler at its after end, and the other pointing towards the centre of the foremost, or driving pair of wheels, with which the connexion was made from the piston rod to a pin on the outside of the wheel. The tender was four-wheeled, and similar in shape to a waggon; the foremost part holding the fuel, and the hind part a water-cask, which primitive plan is still adhered to on the Stockton and Darlington Railway. The blast was produced by steam, the eduction-pipe leading into the chimney. On the day of the trial, this engine was managed by Mr James Stephenson, an uncle of the maker.

The only other engine requiring any particular notice was the Novelty, by Messrs Braithwaite and Ericson. This engine carried its own water and coke without any tender, and the leading feature belonging to it was its lightness and handsome appearance. The whole weight of the engine, without water and coke, was only 2 tons 15 cwt., and deducting from this 16 cwt. 1 qr. 9 lbs. for the weight of the tank, coke-baskets, water and fuel for a journey of thirty-five miles, left the nett weight of its working power only 1 ton, 18 cwt. 2 qrs. 19 lbs., while the engines in use on the Stockton and Darlington Railway at this time weighed 12 tons. It had four coupled wheels, the boiler held about 45 gallons of water; the cylinders were 6 inches in diameter, with a 12-inch stroke.

The boiler, a cylindric one, was placed under the engine-frame; at one end was the furnace surrounded with water, and fed with fuel by means of a hopper passing through the steam-chamber, which was over the furnace. The heated air went along a flue, making three bends backwards and forwards in the boiler, and this flue was made gradually less and less till it terminated in the escape-pipe. The blast was obtained by bellows which threw a strong current of air in at the bottom of the furnace. The connecting rods were moved by means of bell cranks joined by slings to the piston-rod.

The prize of £500 was, as a matter of course, awarded to Mr Robert Stephenson, for his engine, the Rocket. Prior to this competition, the greatest loads which were drawn by locomotives was 43¼ tons gross, engine and tender included, 15 tons at ten miles an hour, or 28¼ tons of goods, including waggons; while the Rocket, in November 1829, weighing only 7½ tons, drew 44 tons gross, at 14 miles an hour, being, exclusive of engine and tender, 36½ tons of goods and carriages; or, in round numbers, the Rocket, only half the weight of the best drawing engine previously constructed, drew one-third more load at one-third more velocity. The principal improvement which led to this great result, was the introduction of tubes in the boiler, by which the evaporating power was increased to three times that of the older engines, with 40 per cent less consumption of fuel. These tubes were suggested by Mr Booth of the Liverpool and Manchester

Railway. The original inventor, however, was M. Seguin, whose patent is dated February 22, 1828, whereas the Rocket was not brought out till October 6, 1829. M. Seguin had never succeeded in getting them tight, through the expansion of the materials. Mr Robert Stephenson, who made several engines for M. Seguin, effected this by hooping them inside, by which means the expansion closed them perfectly.

The engines in the above trial having been limited as to weight, it was immediately perceived that further improvements would result from increasing this, and expending the addition as much as possible in enlarging the evaporating powers of the engines. Hence the boilers have been made much larger, the number of tubes increased, and various other arrangements made conducive to that result; and by these means, the weight of the engines have been brought up by degrees to what they are at present. The number of tubes in the Rocket was 24, and their diameter three inches; the Meteor had 88 of two inches diameter; the Comet, Arrow, and Dart, 90 each, of the same diameter; while the Northumbrian had 132 of 1⅝ diameter.

The highest number of tubes we know of in the English engines is 169, which were tried in an engine built by Mr Robert Stephenson for the Grand Junction Railway. The Planet, which was the ninth engine built by Mr Stephenson for the Liverpool and Manchester Railway, had 129 of 1⅝ inches diameter. The Rocket had an 8-inch cylinder, and 18-inch stroke; her boiler was 6 feet in length, and 3 feet in diameter; the area of her tubes exposed to the heated air was 113 square feet; her driving-wheels were 4 feet 3 inches in diameter, and the smaller pair 2 feet 7 inches. The Planet had an 11-inch cylinder, and 16-inch stroke; the boiler was 6½ feet long, and 3 feet in diameter; the four wheels were 5 and 3 feet in diameter, and the surface of the tubes 370 feet, besides 37¼ square feet of surface exposed to the direct action of the fire. This latter has varied in different engines up to 108¼ square feet, and the area of the tubes has been as much as 641 square feet.

The wear of tubes, and the good performance of locomotives, depend of course greatly on the nature of the water used in them. The Firefly and Skipwith engines used in constructing the London and Birmingham Railroad, had a coating formed round their tubes nearly half-an-inch thick, and in consequence they were so nearly burnt through, that several broke by the force of the steam thrusting out each end of the boiler: they were not more than one sixteenth of an inch thick where they broke, and were found with openings all round them, nearly one fourth of an inch in width; the water being prevented from getting into them solely by the coating round the outside. Rain water is the best of all, where it can be procured, but this will not often be got in sufficient quantity; when stream water is used, it must not be taken from those which run over a lias district, and with either springs or streams passing over or through calcareous matter of any kind; the water should be tested before admitting it in an engine, particularly if the streams run slowly. Throughout the new red sandstone, the water is generally good: a deposit is formed from it; but not a hard one. The safest plan in every instance will be to have, at all the places of constant supply, a proper analysis of the water, by a practical chemist before it is applied to use.

The improvements which had been made in the Planet were very conspicuous. They were, in fact, the combination in one engine of what had previously been known, viz.—the blast pipe, the tubular boiler, the horizontal cylinders inside the smoke box, and the cranked axle, together with a fire box firmly fixed to the boiler. The Rocket's fire box was only screwed against the boiler, allowing a great leakage of air which had not passed through the fire. The Planet was in the Mersey, but not landed, when the Liverpool and Manchester line opened. On December 4, 1830, she took the first load of merchandise from Liverpool to Manchester, consisting of 18 waggons, containing 133 bags and bales of American cotton, 200 barrels of flour, 63 sacks of oatmeal, and 34 sacks of malt, weighing in the whole 51 tons 11 cwts.; and this, with 23 tons, 9 cwt., which was the weight of the waggon, 4 tons in tender, water, and fuel, together with fifteen passengers, making a total of 80 tons, exclusive of the engine, was carried the whole distance in two hours 39 minutes, under the disadvantages of an adverse wind and new machinery, where there was of course much additional friction. An additional engine assisted the train up the incline at Rainhill.

Her maximum velocity on a level, with the above load, was 15½ miles an hour. On the 23d of November, 1830, she was engaged to bring up some voters from Manchester to Liverpool for the election, and her setting out having been delayed so long as to render it necessary to use extraordinary despatch, in order to bring them to the poll in time, she performed the journey between the two places in sixty minutes, including a stoppage of two minutes, the usual time allowed for taking in water on the road.

Among the leading improvers of these machines is Mr Edward Bury of Liverpool, who now contracts for the locomotive power on the London and Birmingham railway. The distinguishing features of his plan are horizontal cylinders: these were first put outside under the framing, but are now enclosed within the smoke-box, which all his engines have, except two made for the Liverpool and Manchester railway. Inside bearings, and cranked axles, and horizontal cylinders, however, were before used by Gurney in his common road engines. Ericson's engine, the Novelty, also had the former. The first engine made by Mr Bury was the Dreadnought, which was started on the Liverpool and Manchester railway, March 12, 1830. She had six wheels, and was much objected to on that account. The next was the Liverpool: this was the original engine made by him with horizontal cylinders and cranked axles. She was placed on the Liverpool and Manchester railway, on July 22, 1830, and had an 18-inch stroke, two pair of six-feet coupled wheels, and 12-inch cylinders.

The great danger in cranked axles is from their breaking, which, with four-wheeled engines, might occasion considerable damage. They have been broken repeatedly; but this has not happened fairly to one of Mr Bury's manufacture: only two have been broken and in both cases from bad welding. One of these, the engine No. 14 on the London and Birmingham railway, was discovered to have been actually running for some time with a broken axle, without its being found out: this arises from the eccentrics being keyed on to the weakest part of the axle, and thus forming a protection against accidents. The above axle had only two-thirds of its section soundly welded when sent from the manufactory.

Mr Bury's engines are now all made with cranked axles and four wheels, the goods' engines being coupled, and the passengers' not. We attribute the success of his axles in some measure to the mode of constructing the framing, and to his bearings being inside the wheels, as any shock from obstructions on the road is thus thrown upon the bearings and not on the crank: the framing is made with great breadth and but little depth, in order to resist lateral shocks; whereas most other makers' have great depth and but little width, which would afford the most powerful resistance to vertical shocks, but, in conjunction with the bearings being outside the wheels, would throw all the lateral ones on the cranks. Many broken axles, however, have been produced by gross neglect in their manufacture. We have seen one which had been welded together, and there was not a junction of a tenth of an inch in the iron, all round; the whole central part being perfectly black, with not the smallest sign of welding. Mr Bury cuts his out of the solid iron, and only welds the part joining the cranks to set them at right angles. Some makers twist the axles for this purpose.

The first eight engines made by Mr Stephenson on the Liverpool and Manchester railway, viz. the Rocket, Meteor, Comet, Arrow, Dart, Phœnix, North Star, and Northumbrian, had the cylinders outside the boiler and worked by a crank pin on the wheel. Mr. Bury's engine, the Liverpool, was then constructed for that railway, and about four months after it had been placed upon the line, Mr Stephenson adopted the crank axle, and placed the cylinders horizontally, with the improvement of putting them inside the smoke-box. This was done first to his engine, the Planet, and it was suggested by a conversation which Mr Stephenson had with Trevithick, when they were on their passage from South America. Trevithick stated there was 40 per cent. increase in the duty of Watt's engines (worked expansively) in Cornwall, from putting a jacket on the cylinders. Mr Stephenson's engines, however, still have their bearings outside the wheels, of which there are three pairs. Mr Bury's and Mr Stephenson's engines contain, in principle, all that is at present effected by any English makers, although many of them have various modifications in the different details. The principal remaining difference between them, besides what we have above described, is that Mr Bury uses round fire-boxes, and Mr Stephenson square ones. All other circumstances being equal, the former must evidently be the stronger. Of those minor improvements which have been proposed by various parties, up to the 1st of January 1839, and which appear to be deserving of more or less attention, we shall now give a short account.

Metallic pistons were first applied to locomotives by Messrs Murdoch and Aiken of Glasgow, in an engine made by them for the Monkland and Kirkintilloch railway, which was set to work in May 1831. There can be no doubt of the economy and great utility of these pistons; and their superiority over the old method of packing has been so fully established, that they are at present in general use.

In March 1831, Mr Robert Stephenson took out a patent for an improvement in the axles. It having been found necessary that the wheels should be fixed to the axles, and the weight of the carriage being supported by concave bearings resting on the upper surfaces of the ends of the axles, a difficulty was found in keeping the working parts constantly yet economically lubricated; the oil supplied to these parts at the points of contact having a constant tendency to escape by its gravity to the more open space at the lower part of the axle, thus producing a considerable and continual waste of oil, and at the same time affording a very imperfect lubrication. To remedy this, Mr Stephenson employed a double axle, consisting of a hollow casing, on the extremity of which the wheel was firmly fixed; through this hollow casing, a solid axle passed, and supported on its ends the weight of the carriage by means of concave bearings connected with springs to the side rails of the carriage, which, for this purpose, was placed on the outside of the wheels. The effect of this arrangement was, that the oil or other unguent used had a constant tendency to accumulate at the precise points at which it was required, namely, on the rubbing parts.

In 1832, Mr Crawshay, the proprietor of extensive iron works at Cyfaithfa, spoke very favourably of the performance of a locomotive built by Mr Gurney, principally with a view to travelling on the ordinary roads, but which was fitted to a railroad at Hirwain; especially as to the ease and economy of first construction, the facility of repairs when required, the extreme lightness, great capability of raising steam, and perfect freedom from danger in the tubular boiler. From January 1, 1831, to January 1, 1832, this engine, which only weighed 35 cwt., including every thing of all kinds belonging to it, with water and fuel in a working state, drew 42,300 tons nett of coal, iron-stone, iron, &c. 2¼ miles in journeys of 20 to 30 tons, consuming during the entire performance of this work 299 tons of coal, value L.47. 17s.; wages of the engine-man, L.52; wages of the fire-boy L.15, 12s. The other expenses are not given, but Mr Crawshay stated that the engine would have drawn twice as much if it had been fully employed.

In 1833 a simple mode of registering the speed of any carriage was proposed, which would also show at what rate an engine had been travelling through every part of its journey. It consisted of a rod turned round by a connexion with the engine shaft, and on the rod a small steam-engine governor was fixed the balls of which, opening in proportion to the speed, rose and sank a point carrying a pencil, and this marked a card which was slowly turned round by a train of wheel work. A curved line was thus traced on the card; consecutive circles gave the various rates of speed; the engine-man could always see in a moment at what velocity he was travelling, and the rate during the whole journey could be inspected by any person at its end, and any irregularity detected at once.

In January 1833, Mr Hancock patented a contrivance for remedying the inconvenience experienced by the formation and adhesion of clinkers on the fire bars, by which the combustion of the fuel is checked, and consequently the production of steam, by which the velocity of the engine is considerably lessened. The usual method is by means of a rake to clear away the obstructions from time to time as they arise; and this is found to be quite sufficient, provided the fireman pays proper attention to his duty. Instead of this, Mr Hancock proposed to draw out the whole floor of bars, and substitute a clean one. For this purpose the bars should be formed in one entire casting, the outer one on each side being cast with teeth under it so as to form a rack: a rail under each of these bars in the fire-box supported the whole floor, and by means of two pinions working into these racks, and turned by a winch, the floor of bars could be withdrawn, and another substituted, by hooking it on to the last end of the set which were to be drawn out.

In July 1833, Colonel Maceroni and Mr Squire patented a tubular boiler composed of 81 upright cylindric tubes, disposed in nine rows, in the middle of which was the fireplace. The tubes were all connected by horizontal tubes at the bottom and top, the lower being a water communication, and the upper a steam communication. To prevent clinkers and preserve the fire bars from being rapidly burned out, they were formed of hollow tubes, through which water circulated to the upright tubes of the boiler.

In October 1833, Mr Robert Stephenson took out another patent for improvement in locomotives, one object of which was, to obviate as much as possible the danger of cranked axles. These, with the four wheeled engines were found at that time to become strained, and sometimes broken, owing, as was supposed, to the great friction between the flanges of the driving pair of wheels and the rails, especially in going round curves or running into sidings, where the centrifugal force would be called into action, and occasion the flanges to bend considerably. It is evident that any bending of the crank axle, although far short of fracture, would occasion such a violent lurching motion, through the wheels being put out of square, that in all probability either the axle must be broken, or the engine be thrown off the rails. To obviate these disadvantages, Mr Stephenson made his driving wheels without flanges, and added a third pair of small wheels to his engines, in which manner they are now made ; the two pairs of small wheels having flanges, and the middle, which is the driving pair, having none. The axles of the small wheels being straight, and consequently stronger than the cranked axles, have been found by experience not to be at all liable to bend; and the driving wheels, together with the cranked axle, being thus liberated from all lateral strains, the whole of which are transferred to the two pair of small wheels, where there is amply sufficient strength to bear them, have been found to stand their work in a satisfactory manner.

The additional pair of wheels also affording the means of adding to the weight, boilers of greater strength and magnitude were now applied to his engines by Mr Stephenson, which would occasion them to last much longer; for of course the larger the entire capacity of the boiler is, the more metallic heating surface it will contain, and consequently render in a great measure unnecessary that intense heat which is so prejudicial to the metal, and which was found to burn out the old boilers very soon. This diminution in the intensity of the combustion had also advantages in another point of view. The jet of waste steam which is thrown into the chimney to produce a rapid draught for exciting the combustion of the fuel, may be diminished in its velocity, and still produce a sufficient effect. This will permit the waste steam from the cylinders to escape with greater freedom than could be permitted with smaller boilers, where a greater heat and a more rapid generation of steam are indispensable to furnish the requisite power.

Three pair of bearing springs were attached to the engine, one over each pair of wheels, causing all the six wheels to bear equally and fairly on the rails, and to ease all jolts and concussions. These springs were, for this purpose, specifically adapted to the respective weight to be borne by each pair of wheels; the main ones, which are impelled by the power of the engine, being in all cases loaded with as much of the total weight as will ensure sufficient adhesion to the rails, so as to prevent any slipping.

In this same patent Mr Stephenson proposed a new mode of stopping the engine by means of brakes, acted upon by plungers in small cylinders, into which the steam could be let in an instant by turning a small cock. The motion of these pistons was communicated to a system of levers which drew the brakes with considerable force against the periphery of the wheels; by turning the handle of the cock in the opposite direction, the steam was allowed to escape from these cylinders into the open air, and the brakes then separated from the wheels.

In October 1834, Mr Hick took out a patent for an engine having three cylinders and a three-throw crank: the steam being admitted only at the top of each cylinder, and always forcing the pistons downward, the bottom of the cylinders being open, and when the pistons were ascending the steam was allowed to escape into the eduction pipe which led into the chimney. The intention of the patentee was to secure, as he supposed, more adhesion between the wheels and the rail, from the power being communicated in a downward direction only; he also anticipated less vibration than when the action of the piston was applied either upwards and downwards, or backwards and forwards. The wheels of this engine were to be formed of a cast iron nave, properly turned and truly bored. This was fitted to receive on each side discs of plate iron instead of spokes; on these discs the external rings and tires were fastened, by first expanding their circumference by heat and then allowing them to contract, so as to receive the edges of the discs in grooves which were turned to receive them; the whole were then screwed together by bolts and keys in the usual manner.

In November 1834, Mr Whitesides of Ayr, in Scotland, took out a patent for an engine in which the axles were to be firmly fixed to the engine, and the springs were placed inside the wheels, the spokes not reaching the nave, but ending at a ring about eight inches diameter, within which the nave played on helical springs fixed to the inner circumference of the wheel at one end, and to the outer circumference of the nave at the other.

In 1835 Mr Baldwin of Philadelphia made several very ingenious attempts at improving the locomotives which were constructing by him for several railroads in America. In the first place, the guides of the piston-rods were made hollow, and these cavities used as chambers for the force pump, thus giving additional strength for the guides, with but little increase in their weight, and dispensing entirely with the frame and fixtures of the ordinary force pumps. Secondly, his pumps have five valves, the one nearest the boiler being loosely swivelled to a stem passing through a steam-tight collar in the top of the valve box, by means of which the valve can be sounded, and in most cases freed from obstructions: the other four are contained in one box, secured to the pump by a stirrup, which can be removed by loosening a single screw, so that the valves can be taken out, cleaned, and replaced in a few minutes, thus almost insuring a certain and efficient supply of water to the engine. Thirdly, the arms of the rock-shafts extend on opposite sides of the fulcrums, and each eccentric rod has two hooks turned in opposite directions, so that it may be geared to either arm of the rock-shaft, the eccentrics being fixed to the axle. When the eccentric rods are geared to the same arms of the valve rods, the motion of the valves corresponds with that of the eccentrics; but if they are geared to opposite arms, the engine is reversed, and if not geared to either arm, the valves can be worked by the hand gear. This method dispenses with much complicated machinery. Mr Baldwin also dispenses with one arm of each crank, fixing the wheel to the wrist of the cranks, which, by this means, are further apart, admitting of a larger boiler, with a better distribution of its weight. The heels and spokes of his wheels are of cast iron, the felloes are of hard wood, on which is a wrought iron tire. This arrangement is found to be advantageously elastic. The steam-pipe is introduced into the boiler through the opening by which it usually communicates between the dome and the cylinders, the throttle-valve being fixed on the steam-pipe. This arrangement allows the pipes to be made without a joint inside the boiler, and no man-hole is required; the juncture between the dome and the boiler being fitted so as to allow the dome to be readily taken on and off, and its aperture used as a man-hole.

Mr Bergin's buffing apparatus, which we have before described, was patented in March; Mr Booth's axle grease in April 1835. In December Mr Blyth took out a patent for a method of retarding the speed of railway trains. It consisted of a friction wheel on the inner side of the nave of the carriage wheel. Around this was brought a band, from whence it was conducted and made fast to the carriage body, in such a manner, that in descending an inclined plane, when the carriage body naturally inclines forwards, it drew by means of the band, the friction wheel against the running wheel, thus creating a retarding force in proportion to the inclination of the plane.

In January 1836, Mr Booth's draw-bar, which we have before described, was patented; and at the same time a new method of stopping trains was proposed by the same gentleman, and included in the above patent. This contrivance was to effect its purpose by checking or stopping the speed of the engine, through the means of a throttle-valve introduced into the blast-pipe, just where the two exhaustion pipes unite into one, and below the place where the pipe is contracted in area, for the purpose of producing the blast. From this throttle-valve a rod passes through the chimney, and is placed within reach of the engineman. By closing this valve, without shutting off the the steam, the pistons are speedily, but not suddenly checked, and the engine is soon brought to a stand, without much violence to the machinery.

Early in the same year, a committee of the city council of Baltimore was appointed to witness the performance of a locomotive, built by Messrs Gillingham and Winans, for the Baltimore and Ohio Railroad Company, by contract, for 50,000 dollars. The weight of the engine was 8½ tons, and the load attached to it was 17¼ tons, including the tender, viz.:—

| | | Tons | cwt. | qrs. | lbs. |
|---|---|---|---|---|---|
| Four-wheeled passenger car, | Paterson, | 1 | 10 | 2 | 0 |
| Ditto | Patapsco, | 1 | 15 | 2 | 0 |
| Ditto | Carol, | 1 | 15 | 2 | 0 |
| Eight-wheeled double passenger car, | | 4 | 17 | 0 | 0 |
| 45 passengers, | | 3 | 0 | 0 | 0 |
| Tender, | | 4 | 7 | 0 | 0 |
| | | 17 | 5 | 2 | 0 |

The four-wheeled cars were capable of carrying 17 passengers each, and the eight-wheeled one 44. With the above load the committee state that the performance of the engine on the Baltimore and Ohio Railroad was as follows:—A plane 2150 feet long, and rising 197 feet per mile, or 1 in 27, for 2050 feet, and 201 feet per mile, or 1 in 26 for 100 feet, was ascended; the impetus previously acquired on the level being lost in the first 300 feet of the ascent, and the engine then steadily progressing to the top at the rate of four to five miles an hour. A plane 3000 feet long, 2800 of which was at the rate of 170 feet per mile, or 1 in 31; 100 feet at 227 feet per mile, or 1 in 23¼; and the 100 feet next the summit at 264 feet per mile, or 1 in 20, was ascended at the rate of 5 to 6 miles an hour, to within 30 feet of the top, when it stopped. The three small cars, weighing 5 tons 1 cwt., were then cast off, and the engine started without assistance, and drew the 12 tons 4 cwt. to the top. The engine was coupled, and had 12½-inch cylinders with a 22-inch stroke. The boiler had 400 tubes, furnishing plenty of steam: the maximum velocity is not given.

In September 1836 a patent was taken out by Messrs Van Wart and Goddard, for a locomotive engine, invented by Dr Church, who had long been labouring to effect steam transit on common roads. The railway locomotive constructed by Dr Church has a very handsome appearance. It carries its own fuel and water, and the engine-man is placed in the front, not behind, as in the usual arrangement. The frame-work and external casing is of sheet iron, the water tank being low down, and outside the wheels. The furnace is nearly surrounded with water communicating with the boiler, and its flues terminate in a series of vertical tubes, which lead to the chimney, and which are also surrounded by the water in the boiler. The cylinders are horizontal, and placed in the fore part of the engine, and there are safety valves to each of the two steam chambers. The wheels are very similar to those of Mr Hick's, being formed with slender spokes made of thin bar iron, fixed at their inner ends into the nave, by having the ends of the metal upset in the shape of a dovetail. These are made fast in the nave by caulking; their outer ends butt against the inside of the rim of the wheel. These spokes have their breadth at right angles to the plane of the wheel, and are boxed in on each side by a circular plate or disc of sheet iron, confined in its situation partly by a series of tenons formed on the edges of the spokes, which pass through corresponding mortices in the discs, and are then rivetted on the outside. Both the discs are attached to the nave of the wheel, by having their inner edges upset in the form of a dovetail. They are then heated and secured, by rivetting over, into slight grooves, against dovetailed shoulders formed round the nave. In the same manner the outer edges of the discs being also upset in the form of dovetails, are inserted into grooves inside the rim of the wheel, by heating the rim, and then shrinking it on to the discs, after which the rim is caulked upon the dovetailed edges, so as to secure the discs firmly.

In December, Mr Harrison took out a patent for an engine, having cogged wheels, with a view to diminish the velocity of the piston the driving wheels of the engine make three revolutions for each complete stroke of the piston; and as they are five feet in diameter, they give a velocity equivalent to fifteen-feet wheels with the same number of strokes per minute. The boiler is placed on one carriage, and the cylinders and machinery on another, each having four wheels. The cylinders are horizontal, and the connecting rods are attached to a double cranked axle, on which is the cogged wheel; this works a pinion on the axle of the driving wheels. The axle of the driving wheels has a motion up and down, as usual, to allow for imperfections in the road; and the cogged wheel and pinion are kept at the requisite distance in gear, by the supports of the cranked axle being fixed over and connected with those of the driving wheels, and thus moving in conjunction with them. Two eccentrics on the cogged wheel axle work the slides with usual levers and hand-gear, and the steam from the cylinders is thrown into the chimney. The two carriages are connected by a bar, and the steam pipes have a ball and socket joint for lateral motion, with a metallic ring packing; they also are composed of two parts, which slide one within the other, allowing by this means a motion in the direction of their length. The tank is under the boiler, and the engine wheels are coupled, in order to have the whole weight, for the purpose of obtaining adhesion. In order to keep the teeth at the right pitch, and prevent backlash, on reversing the motion, the pinion is in two parts, one of which is moveable round the axle, and by means of keys these may be set so as to place the two halves of the teeth a little out of the right line, and thus tighten their action.

In April 1837, Mr Henry Booth took out a patent for supplying the fuel to locomotive (or stationary) engines, by means of a coal-box attached behind the fire-door of the usual furnace, from which the fuel is proposed to be introduced into the furnace, through a long narrow aperture, extending the whole width of the furnace, instead of its being supplied, as now usually done, through the fire door. The door to the coal-box, which is twice the size of the furnace door, being opened, and also the furnace door, the furnace is charged with coal, and lighted in the ordinary way; the furnace door being then shut, the coal-box is also charged with the fuel, which lies on fire-bars, forming an inclined plane; on this the coal descends gradually into the furnace. The coal-box is kept constantly filled up a few inches above the bottom of the water space, or outer casing, under the fire-door, along the whole width of the furnace. When the fuel is properly ignited in the furnace, if the engine is in motion, the shaking of the boiler, furnace, and coal-box, assisted by the inclined position in which the coal lies on the plane, will partially supply the furnace with fresh fuel: any further desirable quantity may be introduced by using a pushing rake between the bars of the inclined plane from below, through the narrow slits made for that purpose in the coal plate; and this fresh coal goes under that which is already ignited, by which means its smoke is in a great measure consumed, at a consequent saving in the consumption of fuel.

During the same month, a patent was taken out by Sir George Cayley for a locomotive engine for either common roads or railways, to be worked by hot air, partially assisted by a small portion of steam, at first starting, or at any difficult points, which steam is to be produced by the injection of water through a rose-ended pipe into the furnace.

In May, Mr Hague took out a patent for carriage wheels. These appear to be exactly similar to those of Mr Losh's, with the latest improvements, except that Mr Hague, after he has bent his iron round so as to form two half spokes and a connecting felloe, (which connecting felloe, when the requisite number are put together, forms the inner rim of the wheel,) welds the ends together before casting the nave round them.

In June, Mr Thomas took out a patent for a mode of economizing fuel, by conducting the waste steam from the engine through the fire bars, which are made hollow, and allowing it to enter among the fuel, through jets, where the vapour becoming decomposed, and forming new combinations with the gases arising from the burning fuel, ignition takes place. We are not aware what is the success of this invention; but a jet of steam thrown into pit coal smoke, in a slanting direction, from above the fire, has been successfully used, both in a great measure to effect the consumption of the smoke, and to produce also a reduction in the quantity of the fuel.

On the 21st of the same month, Mr Harrison obtained a patent for placing locomotives on two carriages instead of one, the boiler and engine being separated, so that each is mounted on its own carriage, and a connexion formed by ball and socket joints, to convey the steam to the cylinders, by which means only the one which required any repairs would be laid up, and the remaining part could be attached to another boiler or engine, as the case might be, so as to lessen considerably the expense of keeping a large number of spare engines, as well as that of sometimes nearly stripping an engine to repair, perhaps, a part of the boiler.

An American engine, made by Morris of Philadelphia, is now on trial for the Gloucester and Birmingham Railway, and is spoken very highly of. It has one pair of driving wheels, and two pair of running ones, very small, and turning with their frame on a pivot, to assist in going round curves. Its performance up inclines, in particular, is spoken very highly of; being 120 tons at 18 miles an hour up the Whiston plane, on the Liverpool and Manchester Railway. It has been got up almost without the use of a file by lathes and planing machines. The pistons and working parts are all outside the framing, which allows the boiler to be very low down. The driving wheels are 4 feet diameter, and the running ones 2 feet inches. It has 76 tubes, and works by a crank-pin outside; the wheel 9 inches from the centre of the axle.

Mr Melling of Liverpool is the inventor of a new motion for opening and shutting the slide valves; but as it requires a drawing to explain it, we must refer to our treatise on the Steam-Engine, where it is figured and described; and we shall close this description of the various attempts at improving the construction of locomotives, by a statement of the proper proportion of tubing for the boilers, so as to afford in the aggregate a maximum quantity of surface exposed to the hot air. Mr Buck, at the Civil Engineers' Institution, January 1839, gives this as follows; namely, that the distance between the diameter of each adjacent tube should be four times the interval between their internal surfaces, by which means from 23 to 26 per cent is gained in evaporating power beyond the usual method.

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## GENERAL DESCRIPTION OF THE PLATES.

Plates I. II. III. exhibit views of a pair of beautiful marine engines, constructed by Mr Napier, for the four

British and North American royal mail steam-ships Britannia, Acadia, Caledonia, and Columbia, plying between Liverpool, Halifax, (Nova Scotia) and Boston, (U. S.) The following are the general dimensions of the vessel and engines.

|  | Ft. | in. |
|---|---|---|
| Length from figure-head to taffrail, . | 228 |  |
| Length of keel and fore-rake, . . | 206 |  |
| Breadth of beam between paddles . | 34 | 6 |
| Depth of hold, . . . . | 22 | 6 |
| Diameter of paddle-wheel, . . | 28 |  |
| Length of floats, . . . . | 26 |  |
| Diameter of cylinder, . . . | 6 |  |
| Length of stroke, . . . . | 6 | 10 |

The power of the engines is about 240 horse power The paddle shafts make 16 revolutions per minute. The tonnage of the vessel by the old law is about 1200 tons.

Plate I. is a side elevation of one of the engines.

Plate II. is the elevation of the crank end of the engines, and Plate III. the elevation of the cylinder end. By an inspection of these engravings it will be seen, that the parts of the engines are sustained by an elegant and rigid Gothic framing, rendering them, notwithstanding the ponderosity of their different parts, entirely independent of the vessel on which they are placed. AA are the cylinders, B the slide-valve casing, C the condenser, D the hot well and air vessel placed on the top of the condenser. E the air-pump, FF the feed-pumps. The moving parts of the engine are as follow:—K the cylinder piston-rod, I the cross-head, H the cylinder side rods descending to the great side levers GGG. Connected with the parts last described are the radius rods of the parallel motion L, the motion side rod L′, and the parallel motion shaft *l*, V the valve or weigh-shaft on which is fixed the valve lever W, whose other end is inserted into a clutch on the slide valve link *c*. On either side of the centre of the great lever depends a side rod *f f*, to work the bilge and brine pumps, and to its extremity are attached the links of the cross-tail of the connecting rods, P the links, Q the cross-tail, R the connecting rod. To the upper end of the connecting rod is attached the crank S; T is the intermediate or crank-shaft, T T′ the paddle-wheel shafts. On the crank-shaft is placed the eccentric U; and *u u* is the eccentric rod working the eccentric gab-lever *v* on the valve or weigh shaft *t* $t^2$. Y *y y* the expansion valve apparatus, *h h* escape valves at top and bottom of cylinders, X paddle wheels, *k* lever for starting the engine, 1 1 steam-pipes, 2 2 waste water pipes from hot well, 3 double force-pump for filling boilers, extinguishing fires, and washing decks, 4 4 engine beams, 5 5 5 5 midship section of vessel, 6 6 thick planks checked in upon and bolted through the timbers thus:—

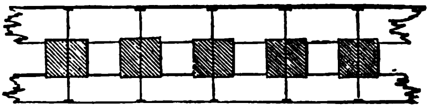

Plate IV. Side and end elevation of one of the engines of her Majesty's mail packet, Urgent, and also of the Actæon, built by Messrs Caird and Company of Greenock. The Urgent plies between Liverpool and Dublin; the Actæon between Liverpool and Glasgow.

Both vessels have been very successful: they are swift boats and consume a small amount of fuel. Their general dimensions are here noted.

| | Urgent. | | Actæon. | |
|---|---|---|---|---|
| | Ft. | in. | Ft. | in. |
| Length of keel and fore rake, | 172 | 1 | 171 | |
| Breadth within paddle space, | 26 | | 25 | 10 |
| Depth of hold, | 17 | 5 | 17 | 3 |
| Diameter of paddle wheel, | 24 | 6 | | |
| Length of floats which in the Urgent are of Galloway's patent in 3 breadths of about [illegible] inches each, | 8 | 10 | | |
| Diameter of cylinder, | 5 | 2 | 5 | 2 |
| Length of stroke, | 5 | 9 | 5 | 9 |

The power of each of the engines is 140 horse power. The paddle shaft makes about twenty revolutions per minute. The tonnage of the Urgent, by the old law, is 502[illegible]—of the Actæon 551[illegible]. A A is the cylinder, C the condenser, E the air-pump, H the cylinder side rods, I the cylinder cross-head, B the valve casing, W the valve lever, W' W the back balance, G G G the side levers, P the cross-tail links, Q the cross-tail, R the connecting rod, S the crank, U the eccentric, N the air-pump side rods M the air-pump cross-head.

Plates V., VI., VII., represent the engines of the Achilles, also built by Messrs Caird and Company, to ply between Liverpool and Glasgow. Plates V., VI., show the two side elevations of one of the engines; and Plate VII. a section of the vessel to a lesser scale, with the engines, paddle wheels, &c., *in situ*. The arrangement of the framing of these engines is highly beautiful.

The entablature supported by the columns, uniting both engines in one design, gives massiness of appearance as well as great strength to the structure. In plate VI. is seen the apparatus for working the engines expansively. On the crank-axle T is placed a series of cams, *t t t* which act upon the roller of the expansion-valve tumbler. Y *y y y* are the expansion-valve connecting rods and levers. Z is the valve chest, and the valve is of the kind called equilibrium valves, or crown valves. The other parts are A the cylinder, B the valve-chest, C the condenser, D the hot well, E the air-pump, F the feed and bilge pumps, GG the great lever, $G'$ its main gudgeon, H the cylinder side rods, I the cross-head, K the piston-rod, LL the parallel motion, M the air-pump cross-head, N the air-pump side rods, O the air-pump piston-rod, P the connecting rod cross-tail links, Q the cross-tail, R the connecting rod, S the crank, U the eccentric pulley or cam, *u u u* the eccentric rod, V the valve-shaft, WW. the valve-lever and counterbalance lever.

Plates VIII., IX., X. The engines exhibited in these plates are a pair of 110 horse power each, constructed by Messrs Fawcett, Preston & Co. of Liverpool.

Plate VIII. shows the side elevation of one of these engines. Plate IX. shows the elevation of the crank end of both engines; and Plate X. the cylinder end of the engines, drawn to a somewhat smaller scale. The letters refer to the same parts as in the engines already described, and it is unnecessary here to repeat the description.

Plate XI. In this plate is given a representation of a single marine engine of 65 horse power, with a stroke of four feet [illegible] side elevation; fig. 2

a plan or bird's-eye view; fig. 3 an elevation of the cylinder end; and fig. 4 an elevation of the crank end. The same letters indicate the same parts as in the former figures.

Plate XII, fig. 1. is an end view, and fig. 2 a side view, of a double towing-engine of forty-five horse power and three feet six inches stroke. The most striking peculiarity of this engine is, that the paddle-wheel shaft is separate from the crank-shaft, and driven by it through the intervention of toothed wheels. T is the crank shaft, with its spur wheel driving the spur wheel of the paddle-shaft $T^2$. The other letters refer to the same parts as before.

Plate XIII. In this plate are represented two engines of direct connexion, constructed by Messrs Tod and M'Gregor, Glasgow.

In figs. 1 and 2 of this plate, the crank S of the engine is placed directly above the cylinder A; the piston-rod K carries a cross-head I, which is guided to move in the vertical direction by two cross guides *g g*, one at each extremity, whose ends slide upon the vertical pillars *p p*, which sustain the framing for the support of the crank-axle. From each end of the piston cross-head depends a side rod HH, whose lower extremity, together with the ends of the side rods PP, which depend from the cross-tail Q of the connecting rod R, are attached to the end of a side lever GG. To the opposite end of the side levers are attached the side rods N of the air-pump, and on either side of its centre the side rods of the feed and bilge pumps F. The parts not already described are *a a* the slide-valve, C the condenser, E the air-pump, S the crank, U the eccentric, and *u u u* the eccentric rod and valve-gear.

In the engine represented in figs. 3 and 4, the piston-rod K terminates in a triangular frame III, from the apex of which the connecting rod R descends to the crank S; and to the extremities of its base are attached the piston-rods OO of the air pumps EE, which are in this case two in number, and situated one on each side of the cylinder. The triangular frame III is confined to move in a vertical direction, by its cross-head *g g* being guided in the slide *p p*. The remaining parts are, A the cylinder, CC the condensers, *a a* the valve-chest, F the feed-pumps, worked by an eccentric *f f*; U*u* the eccentric and valve-gear, and *e e e e* the framing of the engine.

Plate XIV. Fig. 1 of this plate is a side-elevation, and fig. 2 an elevation of the cylinder end, of a pair of marine engines constructed by Messrs Seaward of the Canal Ironworks, Limehouse, for H. M. steam-frigates Gorgon, Cyclops, Prometheus, and Electo. These engines are of a peculiar construction; the crank, as in the engines of the last plate, being directly above the cylinder, the connecting rod only intervening between it and the piston-rod. They are of the class of the vibrating pillar-engines, the pillar which supports the beam turning upon a centre at its lower end. A is the cylinder, B the valve-chest, C the condenser, E the air-pump, K the piston-rod, R the connecting rod, S the crank, GGG the beam, *g* the vibrating pillar, L the radius-rod, N the air-pump side rod, M the air-pump cross-head.

Plate XV. is a side elevation of a locomotive engine. *a*, the steam whistle which is made use of to warn workmen on the road, and persons on the stations, when the engine is approaching. It is formed by a pipe through which the steam is allowed to pass at pleasure, by turning a cock; it then rushes against the thin edge of the upper domed part, which is hollow like a bell, and gives out a clear sound when the cock is properly turned, which may be heard at a very great distance; *b*, an elevated dome, up which the steam pipe rises to nearly the top, to prevent the motion of the engine throwing water out of the boiler. This dome, when taken off, forms the manhole; *c* working safety valve, the lever of which is attached to a spring weighing-machine; *d* lock-up safety valve, which is screwed down to the required pressure by a series of springs; *e*, chimney; this generally has a wire gauze at the top to prevent the escape of sparks, and sometimes a damper to regulate the force of the blast-pipe; *f* smoke-box, in which are the cylinders, the end of one of which is seen at *g*, with the cock *h*, which is to let out condensed water or priming from the cylinder. There is a large door in the front of the engine, opening into the smoke-box, to allow of repairs being made to the cylinders, tubes, &c. inside; *i i i* three gauge cocks, to ascertain the height of the water in the boiler; *k* water gauge, showing in a glass tube the height of the water in the boiler. This gauge communicates by a cock at the top with the steam, and by one at the bottom with the water. It also has a second cock at the bottom, for the purpose of emptying it when necessary; *l* steam regulator, by turning which, the steam is shut off, or let into the cylinders; *m* railing round the place where the engine-man and fireman stand; *n* fire-box, containing the furnace, round which a thickness of about three inches of water circulates from the boiler; the top is also full of water to the height of that in the boiler; *o* supply pipe connected with the tender, from which water is pumped in at pleasure by means of the pumps *p*, which are worked by arms fixed on the piston-rods, and running in guides; *q* the handle which turns the pet cock; this is used by the engine-man to ascertain when his pumps are in proper order, in which case it throws out water, but when they are deranged it gives out steam; there is one on each side of the engine; *r* a cock by which the boiler is emptied, and the engine blown off. Plates also take off at the bottom of the boiler, and open into the mud-holes, which are also used to clean the engine internally; *s s* strengthening rods to the frame-work of the engine; *t t* stays from the framing to the boiler; *u* draw-bar, to which the tender is attached; *v* door to the furnace; there is a similar one to the lower part of the fire-box, which is formed into the ash pit, and is open to the front for the purpose of increasing the draft; *w* the frame-work of the engine. Some makers place this with its breadth horizontal instead of vertical, and Mr Bury of Liverpool has his bearings inside the wheels instead of outside; *x x* the axle guards which play up and down in grooves in the sides of the axle boxes; *y* hook for attaching carriages to the fore-end of the engine; there is a similar one on the other side; *z* one of the buffers. These buffers consist of leather cushions stuffed with horse hair, and their use is to break the shock arising from any concussion which the engine may receive.

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| ... 27, | 8 50 ... | ... 28, | 3 20 P.M. | 18 30 | ... 30, | 8 25 ... | ... 31, | 4 10 P.M. | 19 45 |
| June 1, | 1 25 ... | June 2, | 7 5 A.M. | 17 40 | June 3, | 11 25 A.M. | June 4, | 6 0 A.M. | 18 35 |
| ... 6, | 4 35 ... | ... 7, | 0 15 P.M. | 19 40 | ... 8, | 2 35 P.M. | ... 9, | 9 0 ... | 18 25 |
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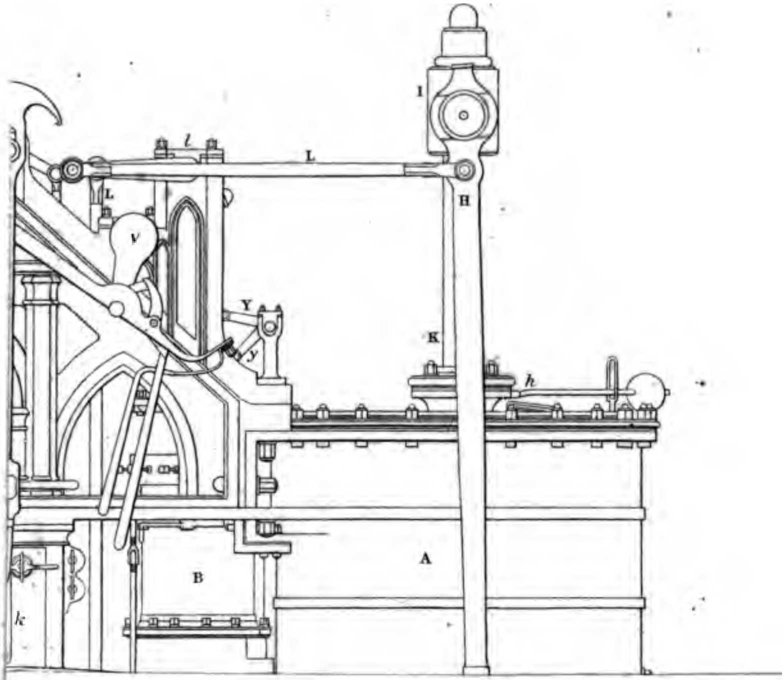

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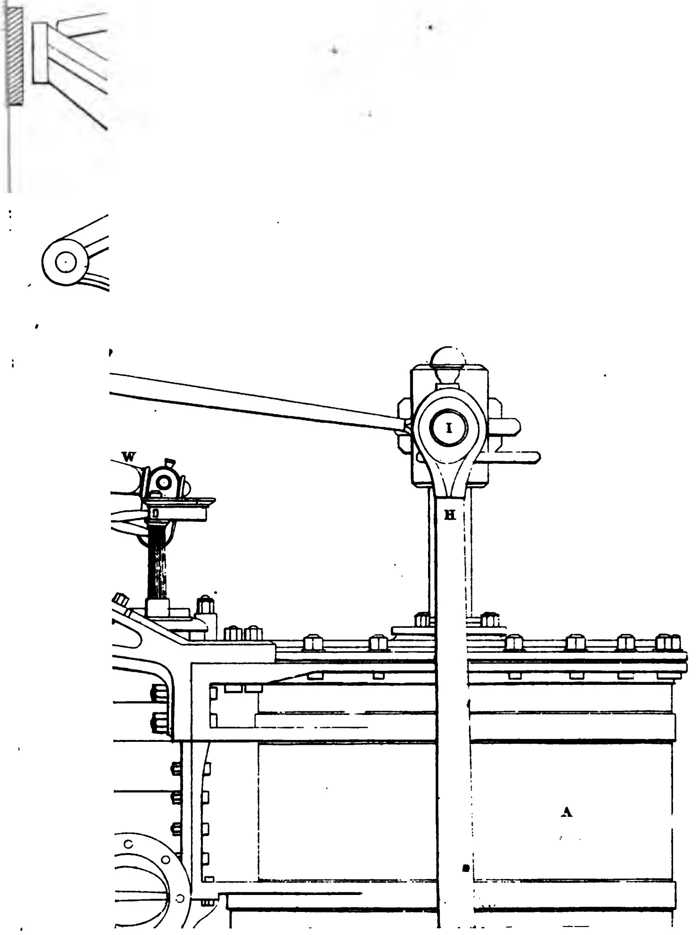

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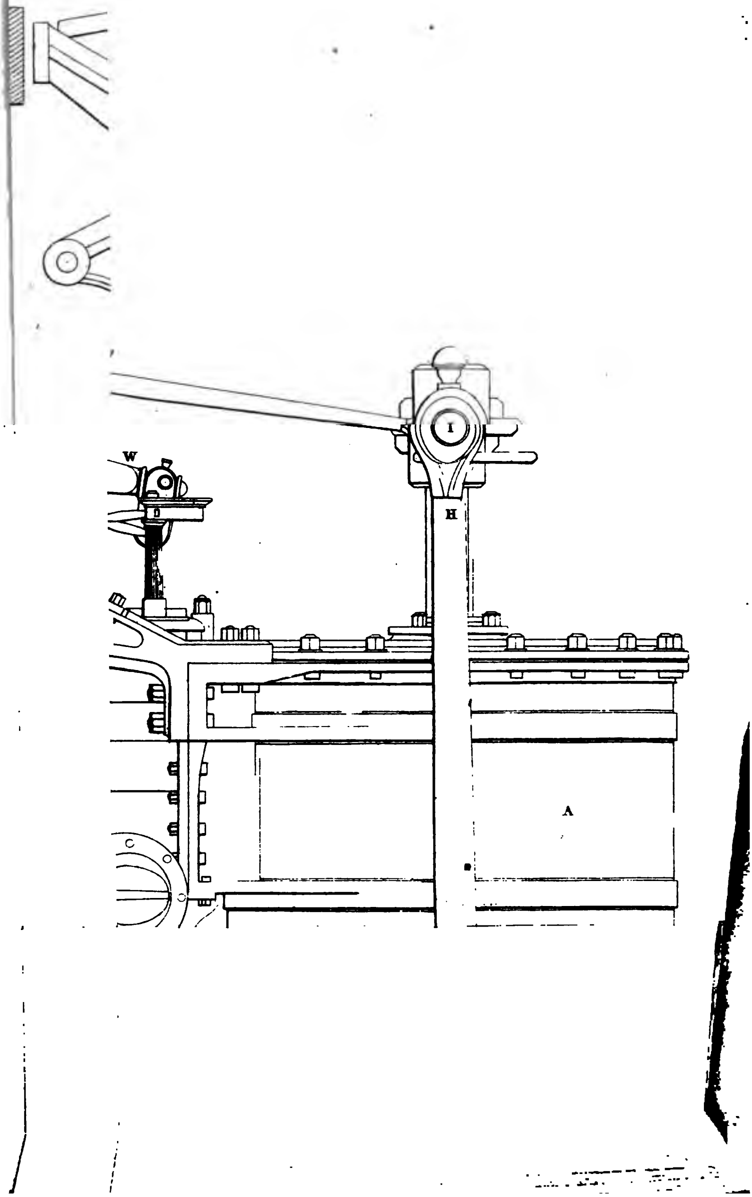

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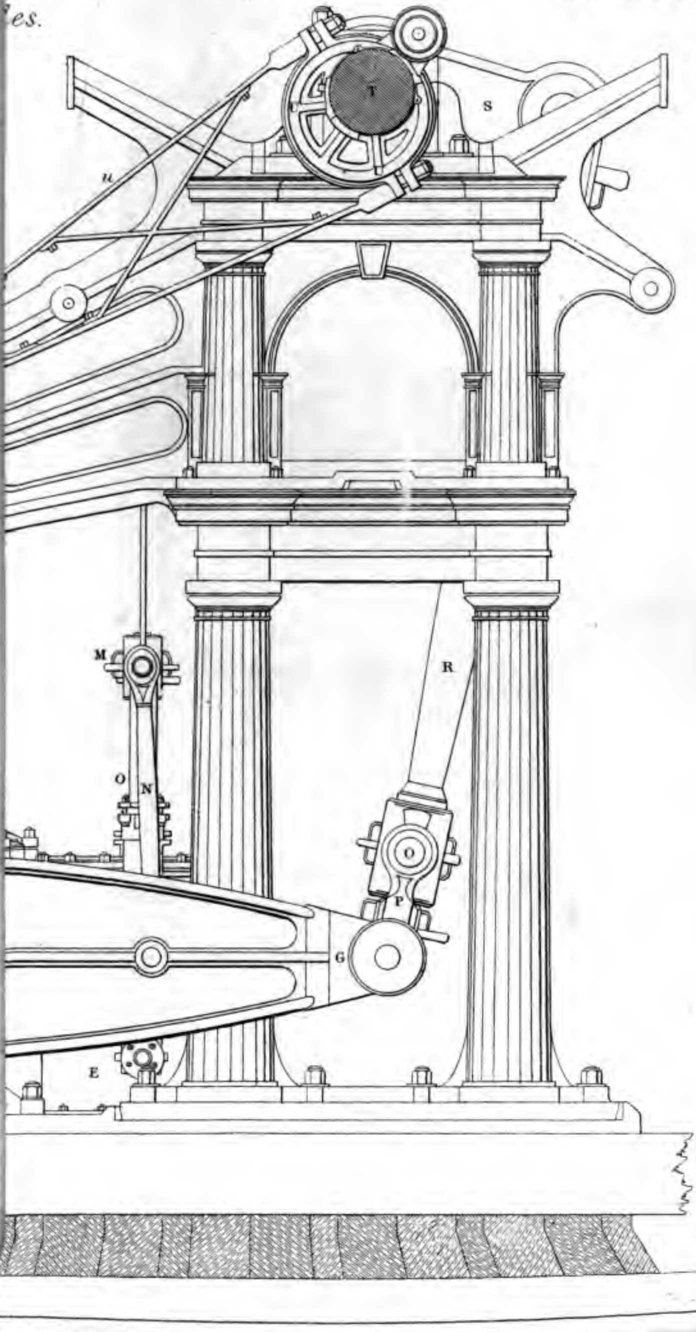

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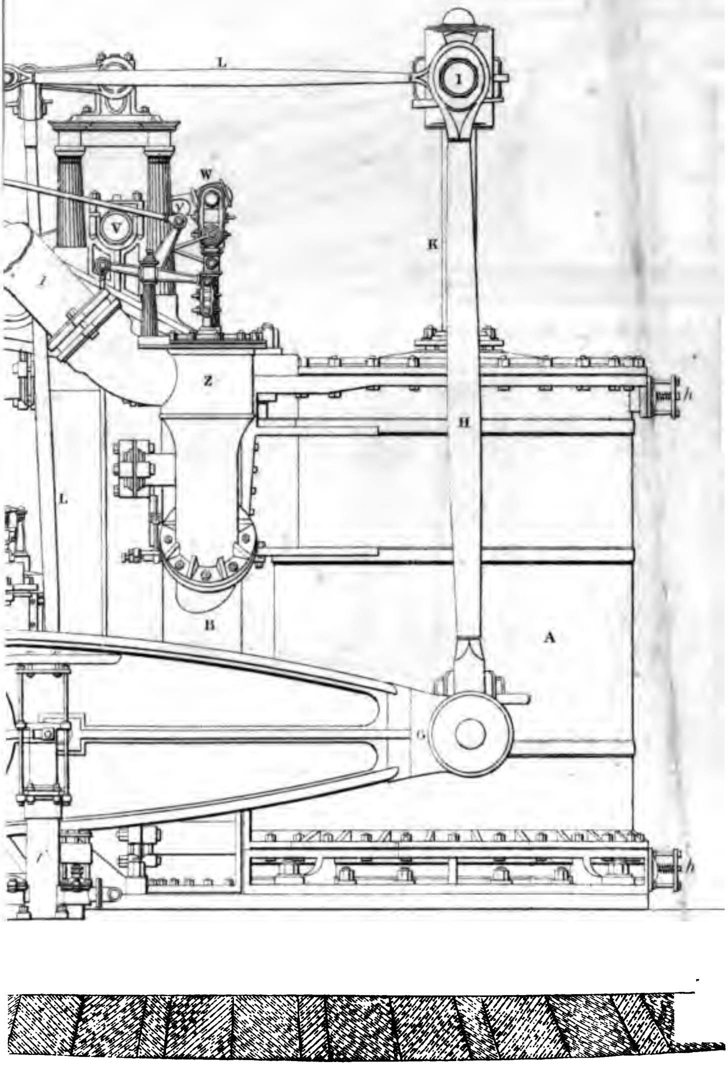

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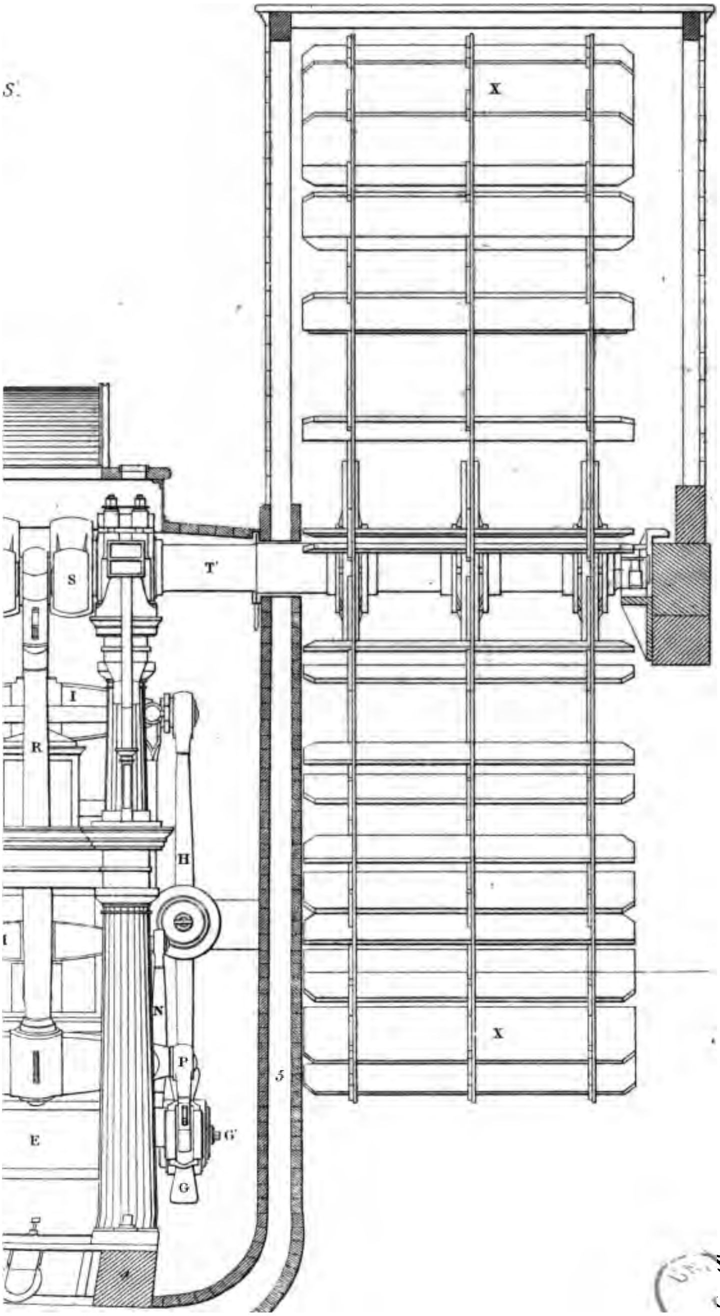

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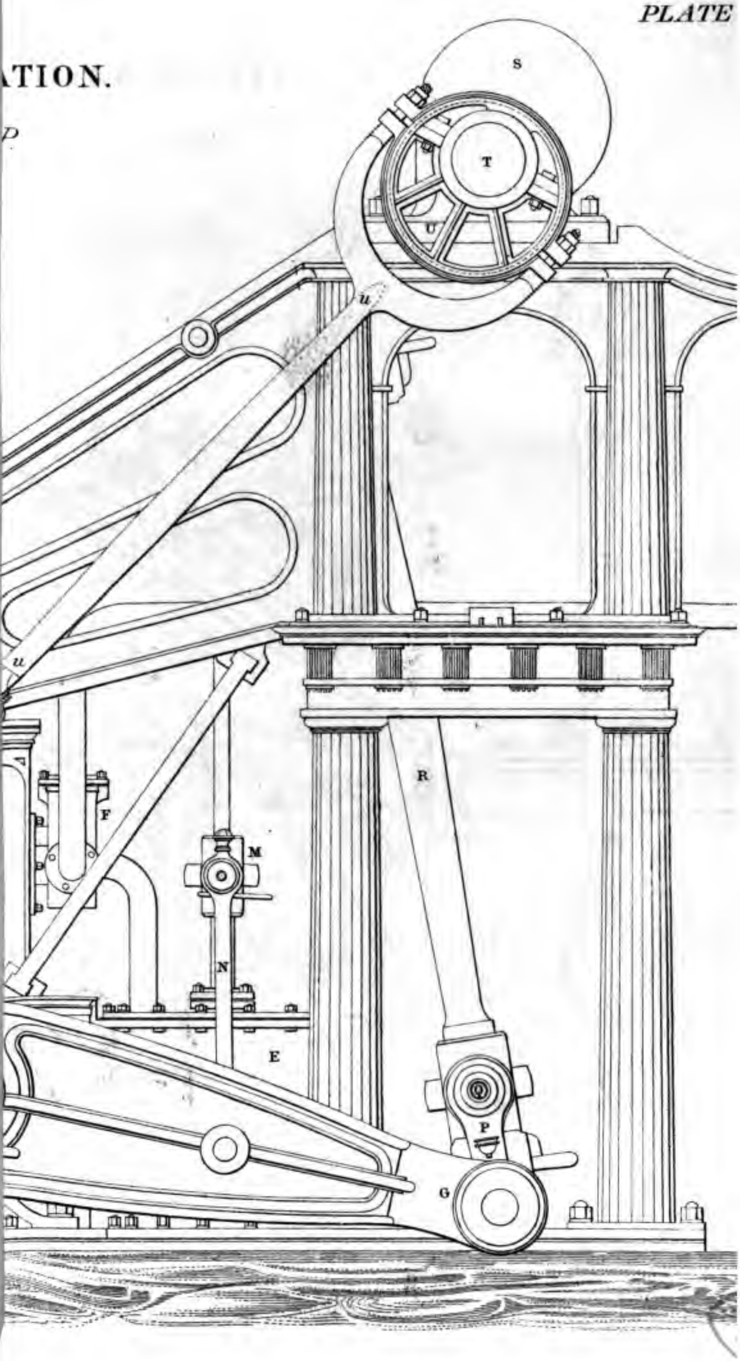

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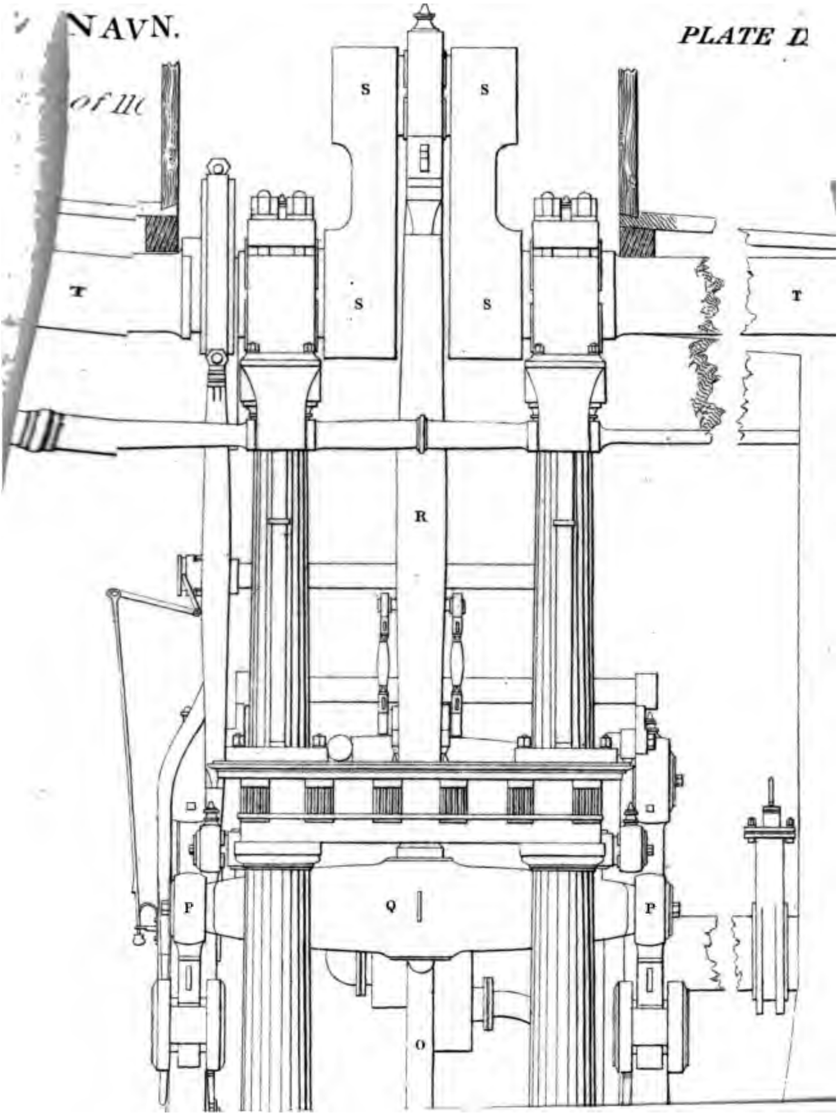

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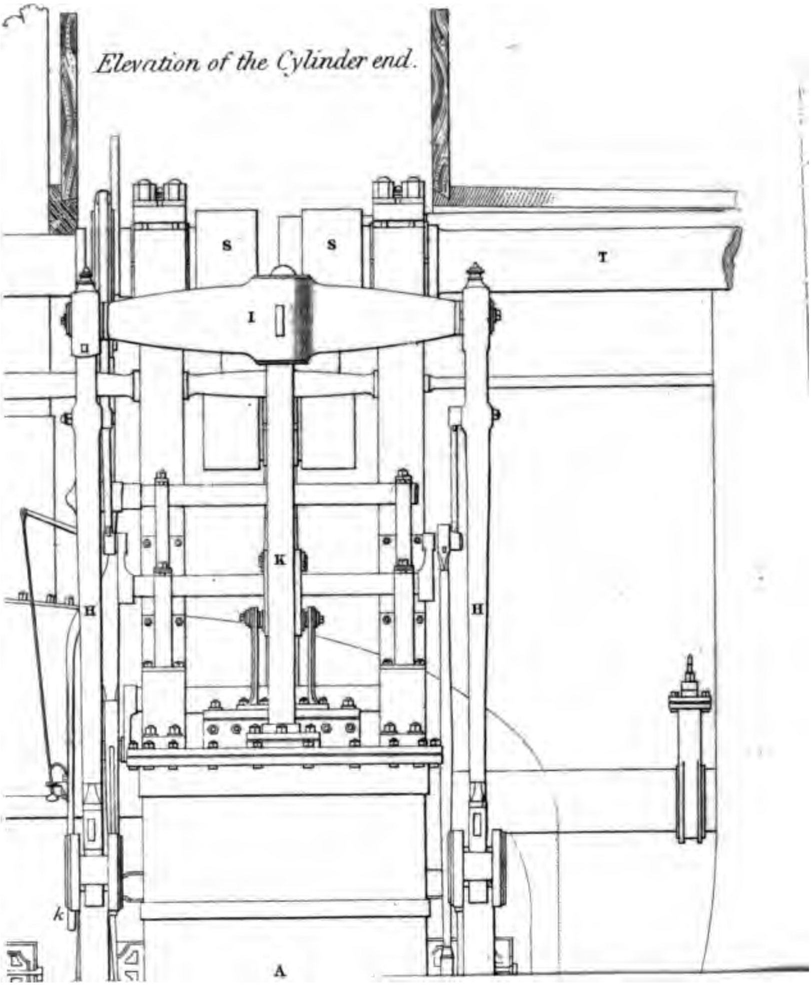

# STEAM NAV

**PLATE XI.**

*Single Marine En*

*Fig. 4.*

*Fig. 1.*

*Side Elev*

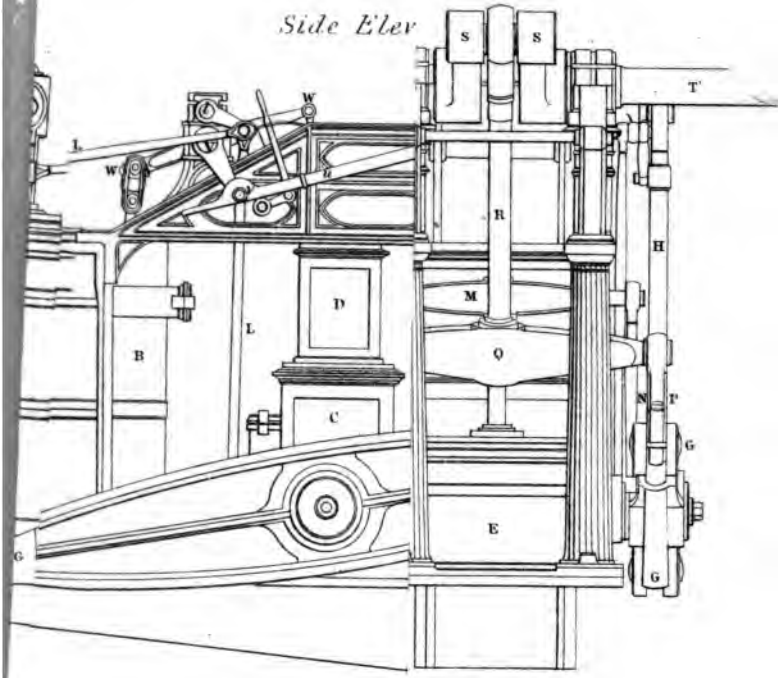

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*Fig. 2.*

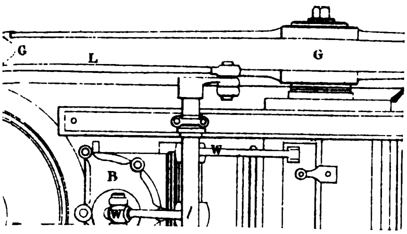

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PLATE XIII.

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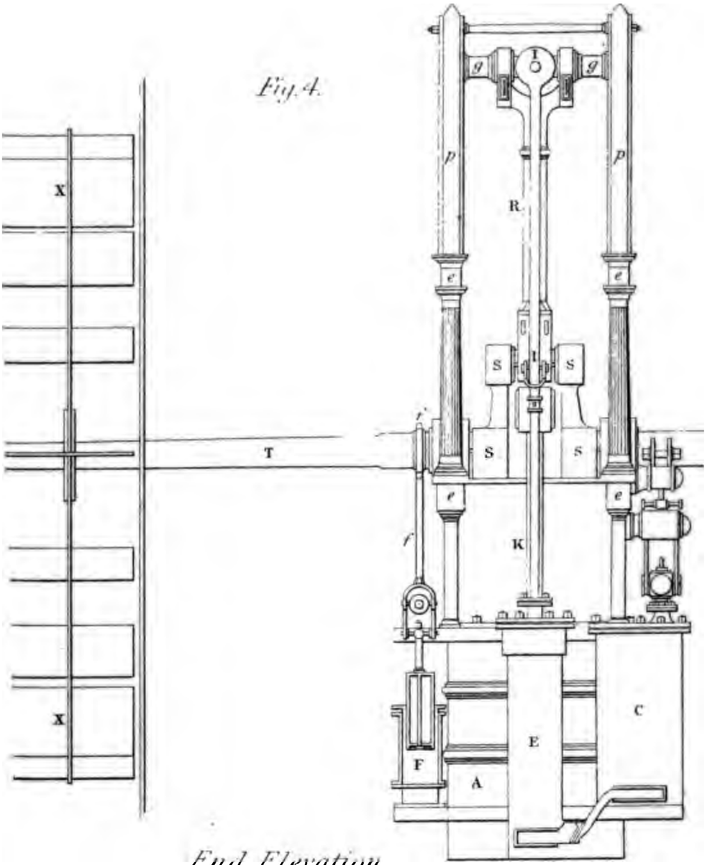

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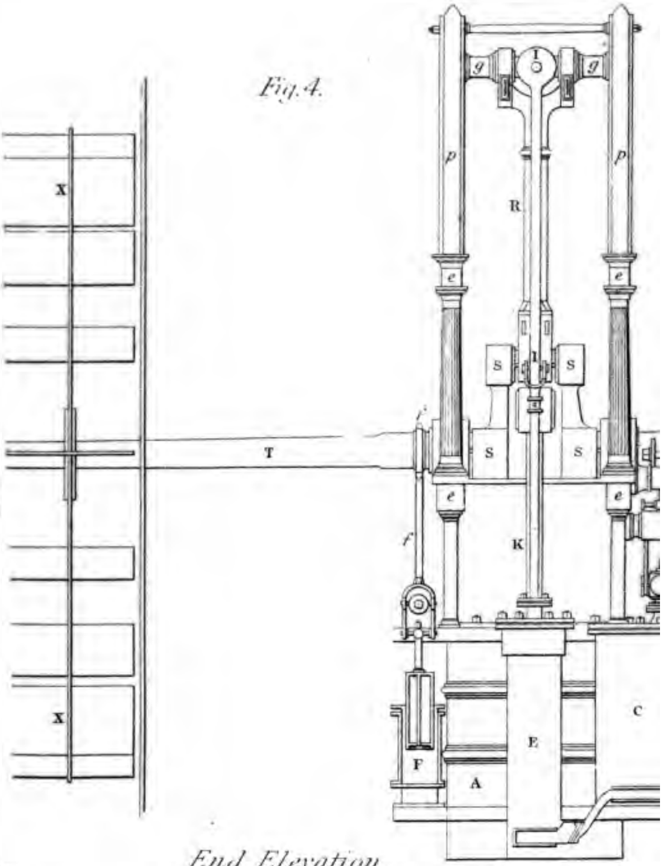

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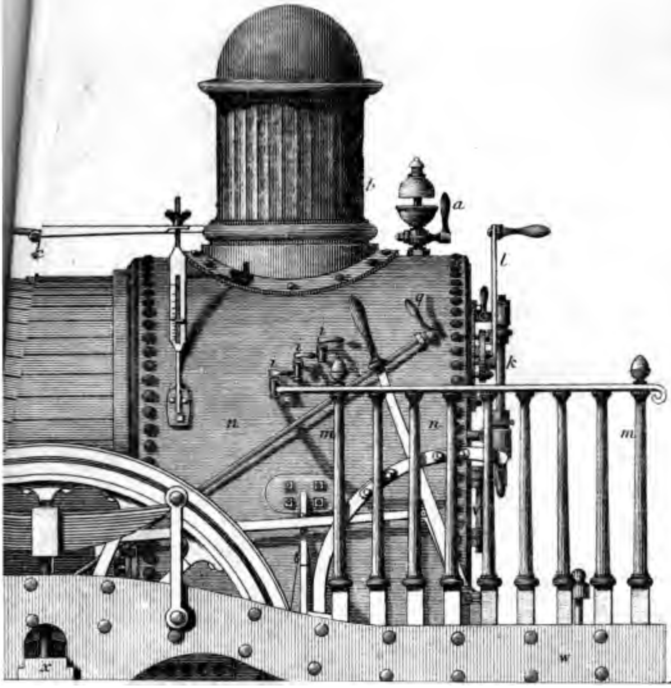

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